THE EFFECTS OF CERTAIN GROWTH REGULATING CHEMICALS ON THE MATURITY OF TOMATO (Lycopersicon esculentum Mill.)

By

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TO MY WIFE, PARENTS AND FRIENDS--
THOSE FORCES WHICH HAVE MOLDED MY
THOUGHT

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Abstract of Dissertation Presented to Graduate Council at the University of Florida
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THE EFFECTS OF CERTAIN GROWTH REGULATING CHEMICALS ON THE MATURITY OF TOMATO (Lycopersicon esculentum Mill.)

By

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The chemicals ascorbic acid, boric acid, calcium chloride, Duraset, Emery C-9, Ethrel, fatty acid ester, IAA and TIBA were evaluated in field trials as to their activity in producing a uniform maturity in tomatoes (Lycopersicon esculentum Mill.). Times of application, concentrations and effects on quality parameters were also evaluated.

A laboratory experiment was conducted to determine the effects of an Ethrel dip on the auxin content of tomato fruit in storage.

A mixed integer programming model was utilized in testing the economic significance of the results of the field trials as well as evaluating the precision of certain of the values included in the model.

The treatments of TIBA-boric acid and TIBA-Ethrel in split applications showed the only significant effects on the total yield by reducing it. The major effects of the other treatments were to alter the yields within the various maturity classes.

Ethrel applied at the time of the fifteenth inflorescence increased the percent yield of the light red through ripe fruit and reduced the percent yield of the mature green fruit in the second harvest. Ethrel applied one week later increased the percent yield

of the light red through ripe and breaker through pink fruit of the first harvest and reduced the percent yield of the mature green fruit of the second harvest. The boric acid applied at the ninth internode followed by Ethrel applied at the fifteenth inflorescence produced an increase in the percent yield of light red through ripe and breaker through pink fruit of the first and second harvest and reduced the mature green of the second harvest.

The effects on the quality parameters were erratic but generally supported the thesis that the early application of Ethrel affected the later fruit and the later application affected the early fruit and the boric acid-Ethrel combination affected both the early and late fruit. The boric acid-Ethrel treatment appears to be the only one with * promise of an economic application.

The laboratory experiment showed an increase in auxins due to Ethrel treatment * at 2 and 3 weeks' extraction after treatment, and a natural increase in auxin at a 1 week extraction that was not evident in the treated fruit.

The economic analysis demonstrated a 11.4 percent increase in yield over the mechanical harvest method alone was required for the utilization of a chemical method with a cost of $132.67 per acre under a 50 acre and 3500 man-hour restriction and with a price of $2.50 per crate. Thus the 2.5 percent increase of the boric acid-Ethrel combination was not sufficient. However, if the price were increased to $3.34 per crate, the treatment would be useful. In addition, a yield of 84.3 percent of the hand harvest was found necessary for machine harvest without chemical treatment to be the only method employed under the previous restrictions.

INTRODUCTION

Tomatoes are an important item in the diet of the United States' consumer. The 1968 per capita consumption of fresh tomatoes was twelve pounds, putting tomatoes after lettuce and watermelons in total fresh vegetable use (165). The major winter sources of fresh tomatoes for northern U.S. markets are the sub-tropical and tropical areas of the western hemisphere, particularly Florida and Mexico (56).

In Florida, the value of the 1968 tomato crop was $92,159,000, comprising 31.3 percent of the total worth of the state's vegetable industry for that year (57).

Recently, Mexican competition has proven a serious threat to the Florida industry which once supplied the majority of tomatoes for the northern markets. In the 1968-69 season, Mexico shipped almost one half of the winter tomatoes; 15,132 carlot equivalents compared to 15,290 carlot equivalents shipped from Florida during the same period (27). The reason for this increase in Mexican shipments can be traced to a gradual improvement in production techniques and a much lower production cost. The primary element in this lower cost is labor.

Mexican growers need only pay $2.10 per day compared to the minimum level of $1.15 per hour in Florida (56). Not only do Mexican growers have the advantage of lower labor cost, they have an almost unlimited labor supply. The scarcity of domestic farm labor in Florida has produced an inability to adequately harvest the tomato crop during peak periods.

Thus, it is imperative that the Florida grower examine all aspects of production with the purpose of severely reducing labor requirements. As an example, it appears necessary that the method of staking tomatoes, being a high labor requiring technique, must be modified or eliminated. However, harvest is still the phase of production with the highest requirement for labor, requiring approximately 25 percent of the total labor need of staked tomatoes and 50 percent of the total in ground tomatoes (26, 28).

Mechanization, whereby capital is substituted for labor, is, of course, the obvious answer. It has been found that mechanical harvesting could reduce the per ton harvest cost of canning tomatoes from $17.19 to $9.84 (128). There are many problems associated with the development of mechanical harvesting techniques. Extensive research in California has resulted in the mechanization of tomatoes harvested for canning; however, only pilot work is being conducted on fresh market mechanical harvest. The greater care required for handling of fresh market tomatoes has slowed the development of mechanical methods. The Florida Agricultural Experiment Station, realizing the urgency of the problem, has embarked on an extensive research project to investigate all avenues available for the mechanization of fresh market tomatoes (70). It was recognized early that one of the primary obstacles to mechanical harvesting is the lack of uniform maturity for a once-over harvest.

There are several approaches to the solution of this problem and the foremost is the development of a suitable determinant variety (155). However, it is well known that breeding programs require long periods to incorporate all of the desired characteristics into a variety. Therefore, it is necessary to examine other methods of promoting uniform maturity as an ancillary program to provide a temporary solution.

While it is accepted that all phases of production exert some influence on the uniformity of growth and maturity of tomatoes (48, 49, 78, 163), the area that has received the most attention and claims of promise is the use of exogenously applied growth regulators (104, 134, 154). The purpose of this study was to examine further the use of synthetic plant growth regulators in this regard. The area of investigation was limited to those compounds exhibiting an effect on the floral zone, as the other types of growth regulators are being examined under the auspices of Florida Agricultural Experiment Station Project 1406. In addition, the effects of these floral zone regulators on the quality of the fruit were monitored.

LITERATURE REVIEW

Morphology

It has been stated that this investigation will concern itself primarily with the floral development of the tomato. This area has been precisely defined (43). Following this, the physiology of the floral zone and ways that have been suggested to chemically modify its behavior are reviewed.

The inflorescence of the tomato is a racemous cyme type. In this case, the apex of the main floral axis (peduncle) terminates in a flower, while six to eleven other flowers arise on lateral branches (pedicels) farther down the axis (43, 135).

Few of the flowers are open simultaneously; thus, the inflorescence is found with a variation of immature flowers, mature flowers, and fruit of differing ages. The tomato flower itself is perfect, hypogynous, regular, pendant and generally six-merous and, when mature, the corolla lobes are reflexed and of a yellow color. The stamens are attached to the base of the corolla tube and are coalesced to form a cone around the pistil. The pistil consists of an enlarged ovary, elongate style and stigma which extends slightly beyond the apex of the androecium.

The pedicel is generally composed of a thick cortex, a ring of vascular tissue and a central pith. About one centimeter below the receptacle along the axis is the abscission zone. There is a reduction in pedicel diameter at this point. In cross section, the zone begins at the epidermis and extends across the cortex to the vascular tissue (it does not extend across the vascular tissue), then through the pith. The cells of the abscission zone are small and flattened (43).

In the abscission zones of apple, gardenia and sweet pea flower buds, which are similar to that of tomato (43, 73, 96, 109, 110, 151), much cellular modification has been outlined, and as most authorities consider all types of abscission in the same light (2, 10, 16), there does not appear to be much danger in comparing these different plant types. Collenchyma cells are in greater abundance than in normal stems, occupying areas normally occupied by sclerenchyma. The cell walls of the collenchyma are thicker and the corners of the cells, normally square, are rounded and the middle lamellae are more prominent. Sclerenchyma tissue, its usual function structural, is reduced in the area of the zone and not present in cortical areas. In the xylem a number of fibers and vessels of the vascular cylinder are replaced by the modified scalariform (elongate) type with scalariform pits. The epidermal cells are elongate and easily separated and the pith is enlarged. All of these modifications serve to weaken the pedicel in the abscission zone.

Electron microscope examinations (86) have shown the indentation of the cuticle has branches which extend through the abscission zone, following the middle lamellae. Thus, separation occurs along these branches. Other ultrastructural details include an increased amount of invaginations of the plasmalemma, and within these invaginations are a number of apparent microbodies with crystalloid cores. Branched plasmodesmata extending into the middle lamellar region and microtubles adjacent and parallel to the plasmalemma are also seen. Another unique structure reported was a membrane enclosed granular component in many of the chloroplasts of the abscission zone. Although the functions of these particular structures are not known, it is speculated (50) that the microbodies contain hydrolytic enzymes.

Flower Production

Kraus and Kraybill (93) distinguished between flower production, flower set and fruit set (fruitfulness). The first term was used in the context of an actual number of flowers (or floral buds) initiated by the plant. In opposition, the second term, flower set, was taken to represent the number of flowers that remained in the inflorescence and did not abscise. Finally, fruit set represented the production and maturation of fruit, whether it was parthenocarpic (the ovary developed without fertilization), normal or the immature fruit aborted.

Went, in a series of experiments investigating the effects of environmental conditions on the growth, flowering and fruiting of tomatoes (174, 175), demonstrated that variations of photoperiod, thermoperiod and light intensity within normal ranges had little effect on flower production. It is well known (162) that aside from varietal differences (92, 74), tomato flower production is generally insensitive to environmental fluctuations. Only when the temperature is reduced to a constant 20°C (174) is the flower production affected.

Beginning with Kraus and Kraybill (93), the effects of nutrition, particularly nitrogen, on tomato flowering have been widely discussed. However, their research concerned the "fruitfulness" of tomatoes and did not deal directly with flower production. They did point out that initiation of floral primordia and blooming were not governed by conditions affecting fruit setting and that, within normal ranges of nutrition, flower production of tomatoes is relatively constant. And as it became evident that cultural techniques affected primarily fruit set, the emphasis of research was directed toward exploring this phenomenon.

Flower and Fruit Set

As alluded to above, the factors affecting flower and fruit set have been much more clearly defined. Went, in the same series of experiments (174), showed that tomato plants grown at low night temperatures (15-20°C) and high day temperatures (26.5°C) had the highest fruit set. He also noted that artificial light during the cool night period inhibits fruit formation entirely. He concluded that the cause of this was the operation of two processes, each with a different optimum temperature and one requiring dark.

Smith (152) in a study of aborted tomato flowers, listed a number of causes of blossom drop and fruit set failure during anthesis. Among these causes were very hot dry or very cold weather, hard rains, thrip injury, deficient soil moisture and rapid vine growth resulting from excessive nitrogen fertilization. Following a histological examination, Smith observed that the embryo sacs of aborting tomato pistils never developed beyond a weak mature egg stage and that the embryo sac and ovules had not developed any farther at 190 hours after anthesis (pollination) than they had at anthesis. He then observed that the slow growth of the pollen tube leaves the flower vulnerable to weather conditions and under adverse conditions the generative nucleus is killed before pollination occurs. Another abnormality noted during his examination was an excessive style elongation during periods of hot weather.

Along these same lines, style exsertion (extension of the style beyond the anthers, thus preventing adequate pollination) and pollen sterility are the primary causes of poor fruit set under extremely low light intensities or high light and high temperature (87). In this review, Johnson also discusses dormancy in ovaries resulting from high temperature and light. When these ovaries are forced to develop without fertilization, they are parthenocarpic. Dormancy of fertilized ovaries also occurs, as a result of low or high temperatures accompanied by low light intensities, high temperature and high light, or when there is large number of fruit already set in the same or adjacent clusters. Abscission of normal flowers, however, is judged to be the major cause of unfruitfulness and this in turn is attributed to the tendency of vegetative plants to limit fruit production.

Haas (65) found under conditions of low humidity and high soil moisture tensions that smaller orange fruits, due to their proportionately greater surface area, lose moisture more rapidly and have a high abscission rate.

The above observations parallel the familiar work of Kraus and Kraybill (93) in which the two authors describe four conditions of the tomato plant in reference to its nutritional status. The four conditions described were:

1. High nitrogen, adequate water and minerals but low carbohydrate. This plant is weakened and non-fruitful.
2. High nitrogen, water and minerals, and available carbohydrates. This plant is barren (flowers fail to mature and abscise) and sterile.
3. Low nitrogen, high carbohydrate. This plant has increased fruitfulness, fertility and is less vegetative.
4. Very low nitrogen, high carbohydrate. This plant is neither highly vegetative nor fruitful.

Kraus and Kraybill explained these conditions by postulating that the balance of nitrogen and carbohydrates was more important than the absolute amounts of either and that an imbalance between the two affected the plant's ability to set and mature fruit.

In an attempt to explain the results of Kraus and Kraybill in cytological terms, Howlett (79) found that carbohydrate deficiency resulted in the suppression of male organs but nitrogen deficiency had little effect.

A valid criticism of nutritional studies of this type, however, is that they were carried out at nutrient levels beyond the range found under normal conditions. Work by Arnon and Hoagland (12) under more optimal conditions failed to show a negative correlation between vegetative growth (high nitrogen) and fruit set.

Leopold and Scott (99), trying to delineate all factors governing fruit set of tomatoes, found that the presence of mature leaves was of primary importance to the development of an adequate fruit set. They also found, as did Went (175), that carbohydrates, particularly fructose and sucrose, were able to substitute to a high degree for the mature leaf in promoting fruit set of excised flowers. Isolating compounds that perhaps were supplied by the mature leaf, they found five other categories of compounds thwich were capable of increasing fruit set. These were: organic nitrogenous compounds, inorganic nitrogenous compounds, organic acids, reducing substances and some inorganic ions. Aerobic conditions were also required. The authors pointed out, however, that due to the large number of compounds acting in this manner and the obvious role of many (fumaric acid, arginine, potassium dihydrogen phosphate) in respiration, that the compounds examined did not play a direct role in fruit set.

Recently Addicott (9) has proposed a scheme whereby the indirect role of these substrates is elucidated as they enter in different pathways of carbohydrate, amino acid and protein metabolism.

Examining the technique of defoliation (pruning) further, Aung (14) reached similar conclusions to those of Leopold and Scott, that the mature leaves exerted the greatest influence on number of blossoms (flower set) and fruit set. He also found that removal of young axillary buds greatly increased the total number of blossoms.

Boron

In examining methods that could be used to enhance fertilization, it was found that boron played an essential role in pollen germination (8). The effect of boron may be three-fold (89). It promotes absorption and metabolism of sugars by forming sugar-borate complexes, it increases oxygen uptake and is involved in the synthesis of pectic material for the wall of the actively elongating pollen tube. It may also play a role in the inactivation of germination inhibitors in tomato pollen. The effect of boron is in excess of any other vitamin, hormone or chemical used in culture solutions due to its generally low concentration in the pollen grain. In a comprehensive review, Gauch and Dugger (61) discuss the application of boron as a foliar spray and its importance in pollen physiology in a number of plants. In this and another paper (60) they postulate the role of boron in sugar translocation and propose the sugar-borate complex mentioned by Johri and Vasil (89). Not only is germination improved with boron treatment, but tube length is significantly longer (161). Field applications to pear trees (soil and foliar) have been found to increase fruit set (17), although under admittedly sub-optimal growing conditions. The enhancement of sugar translocation mentioned by Gauch and Dugger and others (89, 178) would be a beneficial factor in promoting fruit set and maintaining a uniform growth rate throughout fruit maturation. A partial substitution between boron and auxin has been suggested (53), indicating a major role for boron in hormone physiology.

Calcium

A similar role, but not as extensive as for boron, has been shown for calcium in pollen germination (25). It appears that calcium, also generally low in pollen tissue, has a stimulative effect on the growth and germination of low density pollen populations. Calcium is also necessary for mitosis (51). It is possible that calcium may be the governing factor in chemotropism (89) or the growth of the pollen tube toward the ovary. Finally, it is well known (51) that calcium functions as a constituent of cell walls and middle lamella as calcium pectate. This could serve to strengthen the abscission zone (147).

An interaction between boron and calcium in the soil has been shown (90, 133). These workers showed that an increase in calcium reduced boron toxicity symptoms and actually reduced the boron content of the tissue. Increasing calcium had little effect on boron deficiency symptoms and boron was found to have no effect on calcium metabolism.

Abscission

It is evident (87, 152) that the principal mechanism that limits the fruit set of tomatoes is abscission and a good deal of research has accrued on this subject; unfortunately, the major reference concerning physiology is to cotton explants and secondarily to apple fruit and tomato.

A usable definition of abscission would be that it is the morphological cutting away of a modified branch of axis (110), such as a pedicel. Prior to abscission, the cells along the zone elongate and the nuclei increase in size. The epidermal cells become compressed and, in some cases (23, 143), the starch content of the cells increases, cell division occurs and, immediately preceding abscission, the starch in the area of separation is hydrolyzed.

At abscission there is increased pectic enzyme activity (pectase) and dissolution of the lamella and secondary cell wall. Soluble sugars and uronic acids are released and with the separation of the surrounding cell layers the xylem vessels are physically broken by the weight of the flower, fruit or leaf. Finally, periderm formation on the stump occurs (73, 96, 132, 171).

In general, the healthy organ (flower, fruit, leaf) prevents abscission until it senesces or is acted upon by external factors.

Abscission, however, can occur at any period during the development of the flower or fruit; for convenience in discussion, three divisions as to physiological development can be construted (152). These divisions are: blossom drop, i.e., abscission before fertilization, immature fruit drop, and mature fruit drop. The causes of blossom and immature fruit drop can be listed generally as mechanical, general environment prior to fertilization, vegetative and fruiting stages of the plant and artificial factors (87, 152)

Mechanical induction of abscission is merely the result of shear forces produced by high velocity winds, rainfall or cultural disturbance. This process is a function of pedicel length and need not be discussed further.

Environmental and plant stage causes of abscission have already been reviewed under factors affecting failure of fruit set.

Several excellent reviews have been compiled on the physiology of abscission and how abscission is affected by various exogenous factors (2, 3, 10, 44, 85, 140). Low oxygen tensions or high carbon dioxide can prevent abscission; this points out that respiration is required for abscission to take place. Deficiencies of nitrogen, zinc, calcium, sulfur, magnesium, potassium, boron and iron accelerate abscission as do excesses of zinc, iron, chlorine and iodine. High salt or alkaline conditions also produce abscission.

The area that has received by far the greatest attention in abscission research, however, is the effects of phytohormones, both naturally occurring and artificial.

Abeles (2) lists all of the current hypotheses of how abscission is regulated by hormones (this author considers ethylene as a hormone).

Auxin-Ethylene Balance

As proposed by Hall (68), this theory states that since indoleacetic acid (IAA) or other auxins can prevent abscission and ethylene induces abscission; it is the proper balance between the two, maintained in the tissue, that prevents abscission. The absolute amount of either is not considered the important factor. Some of the effects of applied ethylene are to lower endogenous auxin (5) and increase the activity of cellulase (4, 44). It is suggested (7) that ethylene is a hormone in that it stimulates RNA and protein synthesis in receptive (non-juvenile) cotton explants. In this same work it was noted that both the effect of ethylene and abscission were blocked by actinomycin D, which suggests that the proteins stimulated by ethylene are the hydrolytic enzymes which cause abscission (76, 105, 122).

Auxin-Ethylene

Here (16) it is suggested that a continual supply of auxin prevents abscission; when this supply falls below a critical level, abscission occurs. Exogenous application to the distal (leaf or fruit) side preventsabscission. Ethylene is seen as the activator of abscission metabolism and auxin the inhibitor.

Auxin Gradient

This is perhaps the most widely known of the abscission regulating hypotheses. Addicott and Lynch (11) propose that an auxin gradient exists across the abscission zone. As long as the auxin concentration is higher on the distal side than on the proximal (plant) side, there is no abscission. When the level of auxin on the distal side equals that on the proximal or when exogenous, foliar applied auxin raises the proximal level above that of the distal, abscission occurs. Radioactive tracer studies have shown that IAA will not pass through the abscission zone (77). This interpretation has been used (87) in explaining the difference between foliar and inflorescence application of growth regulators in tomatoes. Results from foliar sprays of the synthetic auxin, parachlorophenoxyacetic acid (PCPA) were erratic. It was felt that increased fruit set was due to reduction of vegetative growth or prevention of abscission as this auxin moved into the abscission zone, maintaining an artificially high, but still balanced, auxin level. The opposite effects also could occur, due to abscission acceleration or mortality of the pollen or ovules. Blossom applications were found to be more consistent in increasing fruit set (reducing abscission) by maintaining the normal higher distal concentration. Since development of the ovary then occurred without the necessity of pollination, many fruit were parthenocarpic, a condition long associated with floral "hormone" sprays (64).

Auxin Concentration

In an attempt to explain the opposite effects of differing auxin concentrations, Gaur and Leopold (62) suggest that a high auxin concentration (greater than 15 ppm) inhibits abscission and a lower concentration promotes abscission. While proximal applications were found to be more effective than distal, the same pattern is described by other researchers (21, 22).

Auxin-Auxin Balance

In this proposal (85), it is felt that the leaf supplies a sufficient amount of auxin to prevent abscission until which time it can no longer produce enough, then auxin from other leaves promotes abscission.

Auxin-Senescence Factor

Although similar to the above theory, it is felt that some substance from the aging leaf promotes abscission, rather than translocated auxin (127).

Membrane Integrity

Auxin is thought to act by maintaining the integrity of the membrane and, when the auxin level drops, a loss in membrane integrity is followed by cell separation (37, 142).

Methionine-Auxin

Methionine is felt to act as a methyl donor, and, by methylating carboxyl groups of pectin molecules, overcomes the auxin effect and hastens abscission (183).

Auxin-Gibberellin-Abscission Accelerating Hormone

A conjunctive mechanism is proposed where gibberellin is an antagonist of auxin and a third compound is affected by the action of the two (24, 39, 100, 101).

Endogenous Abscission-Accelerating Substances

Abscisin is thought to be an abscission regulating hormone, and is a product of senescing tissue (3).

Two-Stage Theory

A two-stage action of abscission is said to exist and a high auxin concentration inhibits abscission if the first stage of abscission is not completed. The second stage allows auxin promotive abscission. The two-phase action of auxin in the auxin concentration theory is still proposed, and actions similar to that of auxin are claimed for kinetin. Gibberellic acid was found to promote abscission at all concentrations, and shorten the duration of the first stage (40, 139).

Localized Cellular Senescence

Abscission regulation is composed of two stages. In the first stage, a metabolic difference develops between the cells on either side of the undeveloped abscission zone, giving a mobilization advantage to the proximal side. The second stage then follows, with a mobilization of materials out of the distal tissue, suppression of synthetic activities there, and a transition toward cell wall degradation. The actions of the various growth regulators can be accommodated as preferential effects on the two stages of development. Auxin and ethylene effects are on the second stage as in the Two-Stage Theory (30, 98).

These last two theories, however, do not fit with the practice of thinning early season apples with auxin sprays. Murneek and Teubner (123), preceding the development of these theories, found that the early season treatment was lethal to the developing embryo. They felt that,perhaps with the death of the embryo, a continuous supply of auxin to the abscission zone was lost. Later applications were found to prevent abscission, once the embryo was mature and no longer supplied auxin.

Aging-Ethylene

Examining further the relationship between auxin and ethylene, it was first suggested (118) that ethylene may influence the destruction of auxin. However, with the knowledge that auxin is transported polarly basipetally (150), the concept of ethylene action has been modified to that of an inhibitor (or at least a reducer) of auxin transport. Burg and Burg (36) showed the capacity of the polar auxin transport system is markedly reduced by ethylene. Abeles (1) did not find a transport effect, at least during the duration of a short treatment (three hours). He later (2) explained the positional effect of auxin due to differential transport rates, allowing or prohibiting the effect of endogenous ethylene. Distally applied auxin is able to inhibit abscission, regardless of the accelerated rate of ethylene evolution, by being rapidly transported to the abscission zone. Auxin applied proximally stimulates abscission because it is unable to move as rapidly to the abscission zone, and the ethylene effect becomes dominant. He proposed that the mode of action of other exogenously applied abscission accelerators (abscissin, gibberellin, etc.) is by increasing endogenous ethylene production. Noting that ethylene was found to be most effective on aged tissues, he concluded that abscission rates are determined by an increase in sensitivity of the tissue and proposes the Aging-Ethylene hypothesis.

Compounds Affecting Abscission

Although it is far from resolved which of the above hypotheses is the correct interpretation of abscission, valuable information can be gleaned as to which compounds affect abscission. In summary, ethylene, gibberellins, abscissin, and many auxins--2, 4-dichlorophenoxy acetic acid (2, 4-D), 2, 4, 5-trichloroacetic acid (2, 4, 5-T), napthaleneacetic acid (NAA), IAA and PCPA--under certain conditions, will promote abscission. Auxins, particularly IAA and PCPA, can, in certain instances, prevent abscission. Evaluating other compounds in their abscission activity by acting on either ethylene or auxin (6, 111), it is found that 2, 3, 5-triiodobenzoic acid (TIBA) has an abscission promoting effect (58, 176, 184). The mode of action of TIBA (often called an "anti-auxin") appears to be through the blockage of transport of IAA from its site of production (40, 81, 94, 124, 125), thus producing two effects: a reduction of auxin in remote areas and an increase in local areas. Thus many varied effects can be expected from TIBA application. Two of the effects that are of concern are the removal of apical dominance (as does gibberellic acid) and fasciation or flattened, coalesced tissue. Many claims (81) have been made for the use of TIBA in promoting a large single harvest by eliminating apical dominance and converting all vegetative buds to floral buds. However, since all varieties intended for mechanical harvesting at present (and those proposed) are determinant, apical dominance is not an important factor. The problem of fasciation is of greater concern for if the frequency of fasciated floral buds were to increase with TIBA treatment, the yield of marketable fruits would be affected (18, 177).

Another group of compounds that have been shown to have abscission activity, but have not been widely researched under laboratory conditions, are the phthalamic acids. They have been shown to inhibit terminal growth and cause the development of an abscission zone in beans (119) and inhibit auxin transport in corn (41). These results suggest an action similar to that of TIBA.

Field Applications

Auxins

Since Gustafson (64) showed that synthetic auxins, applied to the style, could cause the development of tomato ovaries without fertilization (and prevent abscission), the use of auxin treatments to increase yield has been widely expounded. However, other than common usage in the San Diego, early market production area of California (172), the use of hormone sprays has had little grower acceptance. There could be many reasons for this: confusion over correct compound and dosage; time, numbers and method of application; and fear of reducing quality.

Many compounds have been screened as to activity in promotion of fruit set and prevention of abscission (13, 35, 85, 185). It appears that any compound meeting the criteria of auxin activity (38) has activity in this regard. Among the more successful are IAA, NAA and PCPA (114, 172, 180). All of these compounds applied at 25ppm have the desired effect of increased fruit set. Unfortunately, at this concentration, these chemicals produce abnormal foliage symptoms when applied as whole plant foliar sprays, and,as a result, only single blossom sprays are recommended (114, 148). This limits the application of these chemicals to areas where the expected higher price for early yields warrants the high labor cost involved in blossom applications. This fact, as was discussed in the introduction, would preclude this specific technique in Florida.

Artificial fruit set is most successful under conditions of low night temperatures (winter or early spring crops) (126) or high temperatures (greater than 90°F) and high light intensities (87). These conditions are typically those conducive to low fertility and high abscission rates, as has already been discussed.

Thus it was shown that any fruit that is forced to develop under these conditions will be seedless or parthenocarpic (88). Parthenocarpy per se may not be an undesirable characteristic, but concomitant developments lead to the unsuitability of parthenocarpic fruits for market, especially when these fruit are handled mechanically. Parthenocarpic fruit, while having the same color and flesh characteristics as normal fruit, have only partially filled locules (113). The fruit is typically puffy (air filled), pointed and subject to premature breakdown (172). This early breakdown is most likely due to premature softening (80). Therefore, fruit set with auxin treatments would certainly handle poorly under the more severe conditions of mechanical harvest. Consequently, any program that is designed to use auxins in promoting an increased yield for a single mechanical harvest in Florida must attempt to avoid the foliar symptoms in the whole plant treatment required by labor cost and unavailability and also to avoid the excessive production of parthenocarpic fruit. The success of this type of program seems improbable with the present knowledge of these compounds.

Although TIBA and the phthalamic acids cannot be defined precisely as auxins, they are included in the same context due to many similarities (158).

Since its development (75), the compound N-meta-tolylphthalamic acid (NMT, Duraset*) has been foliarly applied to tomatoes with success (121, 156, 157, 158, 168) in increasing a single (early) yield and total yield. These experiments were carried out in northern areas under admitted (121) low night temperatures. This suggests an activity similar to auxin. Research in a southern area (54) failed to show an increase in total number of fruit and indicated a softening of the treated fruit. A definite auxin-like activity is found in the ability of the N-arylphthalamic acids to promote parthenocarpic fruit (157, 158). Even though auxin activity is strongly suspected, the higher rates (200 ppm) and foliar sprays without foliar symptoms indicate a much lower activity and possible practical applications. In fact, the material Duraset is available for commercial use.

NMT may not behave entirely as an auxin, though there are indications that it has characteristics in common with TIBA. The results that show increased flower production (75, 157) were conducted primarily with indeterminant and semi-determinant varieties. This would implicate NMT in concelling apical dominance, an action also attributed to TIBA. This is not a clear-cut response, however, for some varieties that did demonstrate an increased number of flowers were determinant.

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*Naugatuck Chemical Division, U.S. Rubber Co., Naugatuck, Conn.

In many of the above experiments, increasing early yield was the primary objective instead of increasing uniformity. Therefore, it is necessary at this point to make a distinction between early yield and uniform yield and clarify the relationship between the two. Early yield refers to the fruit harvested first, early in the season. It is important, especially in winter and early spring production areas, because the early fruit brings the highest market price. The fruits harvested for the early market are obviously those from the first cluster and typically the yield is small. Chemical techniques designed to increase the early yield are aimed at increasing the fruit set of the first cluster.

Uniform yield, on the other hand, refers to the amount of fruit of the same physiological age. Already stated, the goal in artificially increasing the size of the uniform yield is to increase the number of fruit set at any one particular time and carrying this fruit load through to harvest. Therefore, techniques devised for increasing the early yield could also be applicable to increasing uniform yield.

Little field work has been conducted with TIBA applications on tomato; however, to reiterate the remarks made under effects on abscission, TIBA has an anti-auxin effect in promoting abscission and causes increased flower production in non-determinant varieties (81, 184). Problems that could arise with field application would be expected foliar symptoms. Symptoms such as reduction of leaf area, reduced internode length and fasciation could seriously impair the yield and quality of the treated fruit.

Gibberellins

Gibberellins generally have a wide spectrum of growth responses (181). Among the flowering responses is promoting the fruit set of tomatoes. Rappaport (131) found with twice weekly applications of 100 and 200 micrograms per plant (foliar application) that stem elongation was increased. Flowering was hastened by three to six days without affecting number of nodes with 25-100 micrograms and normal and parthenocarpic fruit set was increased by 1-500 micrograms per ml. The flowering response, then, is very similar to that of auxins. The increased parthenocarpy could well be due to the heterostylus (style exsertion) condition found by Bukovac and Honma (31) after gibberellin treatments. Other gibberellin effects are not similar to auxin. Although gibberellins have been found to have an opposing effect to that of ethylene in delaying senescence (suppress fruit ripening) (52, 144), they still accelerate abscission (138). Prior research in Florida (59) has failed to show any beneficial effects from gibberellin treatments on tomatoes, and, in fact, a yield reduction was reported.

Ethylene

Since ethylene is a gas, obvious application difficulties have prevented field experiments. Now, a liquid formulation is available that produces much the same effects as ethylene gas (42, 141, 169) and does, in fact, accelerate the ripening of tomatoes (141) parallel to the manner of ethylene. This material, 2-chloroethylphosphonic acid (CEPHA, AmChem 66-329, Ethrel),[1] has been shown (170) to evolve ethylene gas on an almost one to one molar ratio when titrated with NaOH. With a material such as this it is possible to make field applications as foliar sprays. Ethrel was found not to initiate growth of emasculated flowers or increase the growth rate of pollinated or parthenocarpic tomato fruit. The only flowers that were induced to abscise were unpollinated, mature flowers (84). However, some fruit abscission-inducing chemicals,such as ascorbic acid, have been thought to act through a resultant increased emission of ethylene (45). Ethrel did not have any effect on fruit size but accelerated ripening by five to six days. Whole plant sprays of 1000 ppm applied to five-leaf stage plants caused inhibition of terminal bud growth and arrested growth for two weeks followed by abnormal growth of many lateral buds. When applied to later stages, these effects were not observed, and only the typical ethylene symptoms of epinasty were seen (107, 136, 149).

Further evidence of the ethylene-gibberellin antagonism is presented by Robinson, Shannon and De La Guardia (137) when Ethrel treatments were seen to modify andromonecious cucumber line by initating the production of perfect or female flowers.

Ethrel applications would then have two-fold effects. By hastening the ripening of mature green tomatoes, ease of sorting could be increased; those fruit too mature for shipment to fresh market could be used in canning operations. Secondly, by thinning those blossoms which were at anthesis, a more uniform yield could be obtained.

The treatments will have little effect on the immature fruit since it has been demonstrated (106, 129) that ethylene treatments will not ripen immature fruit, only force color development. Difficulties that arise are the tendency to "shatter" or abcise prematurely during harvest and the poor handling characteristics of the riper fruit (19).

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[1] AmChem Products, Inc., Ambler, Pa.

MATERIALS AND METHODS

Selection of Chemicals

In order to present the development of this project designed to produce a temporary method, with present varieties, of promoting uniform fruit set and maintaining that set through to a uniform maturity, the criteria of selecting materials are outlined below.

- I The techniques explored were in the area of chemical growth regulators directly affecting the fruit set or obscission process.
- II The chemicals tested have shown promise in this regard.
- III The desired characteristics of the chemicals include:
  - A. Desired results
    - 1. Significantly increase single yield
      - a. Increase fruit set at any one time
      - b. Reduce fruit set at other times
  - B. Ease of application
    - 1. Low labor requirement
    - 2. Broad application period
    - 3. No special equipment requirements
  - C. Ease of procurement
    - 1. Commercial availability (registered for use)

  2. Low cost

D. No deleterious effects

  1. Foliar symptoms
  2. Quality of fruit
    a. Handling
    b. Consumption

The materials selected for testing were:

Ascorbic Acid (vitamin C)

Boron (boric acid, H_3BO_3)

Calcium (calcium chloride, $CaCL_2$)

Duraset (N-meta toylphthalamic acid)

Ethrel (chloroethylphosphonic acid)

Gibberellin (gibberellic acid, GA_3)

IAA (indoleacetic acid)

TIBA (2, 3, 5-tri-iodobenzoic acid)

Also included were two compounds submitted for testing by Dr. H. H. Bryan, Subtropical Experiment Station, Homestead, Florida:

Emery C-9[1] (formula not known)

Fatty Acid Ester[2] (formula not known)

Fall 1968

Preliminary Field Screening

On August 15, greenhouse grown transplants of the variety Floridel were mechanically transplanted into single rows in the field at the Horticultural Unit experimental farm of the University of Florida, Gainesville. The row spacing was 6 feet center-to-center. The beds were raised 3 feet wide with 18 inches for the in-row spacing. The soil type was an Arrendondo fine sand with a pH of about 5.0 to 5.5. Prior to planting the land was fumigated with 20 gallons per acre of D-D and 1,200 pounds per acre of 6-8-8 fertilizer with 40 pounds per ton of FTE 503 were applied in bands. The microelement analysis of this fertilizer was then 3.0 percent B, 3.0 percent Cu, 18.0 percent Fe, 7.5 percent Mn, 0.2 percent Mo and 7.0 percent Zn. About midway in the season the crop was sidedressed with an additional 800 pounds per acre of 15-0-15 fertilizer. Overhead irrigation was used to supplement natural rainfall which was generally heavy. Weekly applications of a Sevin-Zineb combination at 1.25 pounds per 100 gallons and 2.0 pounds per 100 gallons respectively were made. These applications were made with a tractor drawn sprayer of the blower type at a rate of 100 gallons per acre. Cultivation was accomplished by hand and mechanical means. The plants were not staked.

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[1] Emery Industries, Inc., 4300 Carew Tower, Cincinnati, Ohio.

[2] Procter and Gamble Co., 301 E. Sixth St., Cincinnati, Ohio.

The treatment plots were 30 feet long in the row and replicated three times in a random pattern. The chemical treatments were applied with a 1 gallon stainless steel Hudson pneumatic sprayer. A 4 liter mix of the chemical was made for the three replicates with 0.1 milliliter Triton b-1956 per liter as a surfactant. Application was made by spraying to foliar run-off according to the rates and times appearing in Table 1.

As this experiment was meant only for initial exploration, no combinations were used; the experimental design was a five x two x two factorial with five chemicals, two rates and two times of application. The concentrations were chosen to bracket those used in previously reported works (87, 172, 179, 180). The times of application

Table 1

CHEMICALS, CONCENTRATIONS AND TIMES OF APPLICATION USED IN THE FALL 1968 EXPERIMENT

First Bloom	Second Bloom
Duraset (100 parts per million)*	Duraset (100 parts per million)
Duraset (300 ppm)	Duraset (300 ppm)
Emery C-9 (0.5 per cent)**	Emery C-9 (0.5 per cent)
Emery C-9 (1.5 per cent)	Emery C-9 (1.5 per cent)
Ethrel (200 ppm)**	Ethrel (200 ppm)
Ethrel (600 ppm)	Ethrel (600 ppm)
Fatty Acid Ester (0.5 per cent)**	Fatty Acid Ester (0.5 per cent)
Fatty Acid Ester (1.5 per cent)	Fatty Acid Ester (1.5 per cent
IAA (10 ppm)*+	IAA (10 ppm)
IAA (30 ppm)	IAA (30 ppm)
Control--no applications	

* Weight by Volume determination

** Volume by Volume determination

+ Solutions prepared by disolving 10 and 30 milligrams IAA in 10 and 30 milliliters of 95 percent ethyl alcohol respectively and then bringing to 1 liter volume with tap water were chosen, following the recommendations of Johnson (87) and Singletory (148), as when the majority of flowers had developed in the first and second inflorescences: or at about two and four weeks after transplanting. Lack of space prohibited the screening of all materials selected at this time, and although the activity of IAA was well defined (87) it was included as a treatment for a check on application methods and times.

The fruit was harvested prematurely on November 5 in order to avoid a predicted frost. The original criterion for harvest was for 10-20 percent of the control fruit to be ripe. All fruit were harvested and a count was made of the number of fruit from each treatment in each of the following classes:

1. Green
2. Mature Green through Pink
3. Light Red and Ripe

These classes were according to the categories as described by the United States Department of Agriculture (164). The discrimination between green (immature) and mature green fruit was made on the basis of size (fruit smaller than 2 inches in diameter were excluded) and subjective maturity measures, such as firmness (overly firm fruit, suggesting inadequate internal jell formation,were excluded) and skin development. An informal check of the reliability of these criteria by observing ripening ability proved this method workable and consistent with others (46, 103, 182).

A subsample of 20 fruit of U.S. Number 1 grade and uniform in size and maturity (breaker stage as defined by the U.S.D.A. (164) from category 2 above) was taken from each treatment. These subsamples were treated with 50 parts per million of Chlorine (as Sodium Hypochlorite) and removed for quality evaluation.

Quality Evaluation

Eight of the chlorine treated fruit were selected from each subsample, placed in one gallon glass contoiners and an airflow of 13-15 liters per hour was directed into each container. The containers were placed in a darkened room and an attempt was made to maintain a constant temperature of 68°F but ± 10°F fluctuations were noted. Ripening characteristics and ripe fruit quality were monitored only by observations.

Statistical Evaluation

Yield data of each category and total were analysed using a one-way analysis of variance, and individual mean differences among treatments for each category and total were determined with the Duncan's Multiple range test as described by Steel and Torrie (153).

Spring 1969

Field Plots

The variety Tropi-Gro was direct seeded in the field on March 12. The row spacing was again 6 feet center-to-center on raised, 3 feet wide beds. However, in this experiment the beds were covered with a black polyethylene mulch and planting was accomplished by cutting holes in the plastic at 15 inch intervals and placing two to three seeds per hill. The soil type used in this experiment was a Leon fine sand with a pH of 4.5-5.0 on the Horticultural Unit of the University of Florida. Preplant fumigation and initial fertilization were carried out as before, although side-dressing was done with 1000 pounds per acre of 6-8-8 fertilizer. Insect and disease control and irrigation were as in the fall 1968 experiment but supplemental irrigation was more frequent during this season due to the normally low rainfall.

The experimental units were plots 50 feet long in the row under a completely random experimental design and replicated three times.

Treatment applications were made as before with the hand carried sprayer. For this experiment, however, Triton X-100 was used as the surfactant. In addition, it was found that about 1.2 liters of solution per plot were sufficient for complete wetting of the plants in early stages; later on, 2.0 liters were required.

The chemicals, concentrations and times of application appear in Table 2. Besides the treatments appearing in Table 2, non-replicated applications of gibberellic acid (35 ppm) and ascorbic acid (10,000 ppm) were made at third bloom plus one week for observational trials. The terms first, second and third bloom are for convenience; a more precise definition of these periods was made. First bloom corresponded to the fourth to fifth internode; the flowers of the first inflorescence were formed but not open. The second bloom was defined as occurring at the eighth to ninth internode. Finally, the third bloom was considered as when the fifteenth inflorescence was mature (the sixteenth inflorescence was open but not mature) or about two weeks after the second bloom. The treatment made one week following the third bloom corresponded to the time when this variety ceased its bush-like appearance and became more prostrate.

In order to alleviate the problem of differentiating immature green from mature green, two harvests were made. The first harvest was carried out when an estimated 10 percent of the fruit were completely ripe. This harvest was conducted on June 16, and the only fruit harvested were those between the breaker stage and ripe. The fruit were then sorted into the following three categories:

1. Breaker
2. Pink
3. Light red and ripe

Table 2

CHEMICALS, CONCENTRATIONS AND TIMES OF APPLICATION USED IN THE SPRING 1969 EXPERIMENT

First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week
Duraset (200 ppm)*			
Duraset (200 ppm)		Ethrel (1,250 ppm)**	
Duraset (200 ppm)	Boric Acid (20 ppm)*		
Duraset (200 ppm)	Boric Acid (20 ppm)	Ethrel (1,250 ppm)	
	Boric Acid (20 ppm)	Ethrel (1,250 ppm)	
		Ethrel (1,250 ppm)	
			Ethrel (1,250 ppm)
	Boric Acid (20 ppm)		
	Calcium Chloride (20 ppm)*		
	Boric Acid (20 ppm) plus Calcium Chloride (20 ppm)		
Control--no applications			

* Weight by Volume determination

** Volume by Volume determination

The weight of fruit in each one of these categories was then taken. Twenty-five fruit, U.S. Number 1, and of uniform size and maturity were subsampled from the breaker class, dipped in 50 ppm chlorine and placed in a dark ripening room at 68°F and 80 percent relative humidity. The fruit were later removed for quality evaluation.

Eight days after the first harvest, a second harvest was conducted; this time all fruit were harvested. Since this harvest did require the separation of mature green from immature green, the criteria used in the fall 1968 experiment were again employed to separate the fruit into the following categories:

1. Immature green
2. Mature green
3. Breakers
4. Pink
5. Light red and ripe

The weight of fruit in each class was taken and the subsample of twenty-five fruit in class three was taken and treated as in the first harvest.

Quality Evaluation

Bio-yield point

After 12 hours in the ripening room, five fruit were removed and the bio-yield point,as described by Keener (91), of the whole fruit was determined with an Instron stress-strain analyser equipped with a tip constructed to the dimensions of those found on the Magness-Tayler pressure tester (112). The fruit was positioned in a shallow dish filled with moist, fine sand that offered good support. This dish was then placed on the load cell anvil and the cross-head was allowed to descend at a speed of one inch per hour. When the bio-yield point was evidenced by a peak on the chart, the cross-head was reversed. In order to get an estimate of skin strength, an area on the tomato, slightly larger than the cross-sectional area of the penetrating tip (seven sixteenths inches), was peeled and the difference between the bio-yield force of the peeled section and the bio-yield force of an unpeeled section 180° opposed on the same fruit was taken to represent the skin strength. This method was used instead of the puncture method evaluated by Voisey and Lyall (167) in order to avoid the laborious procedure of providing a satisfactory sample of skin.

The remaining fruit were allowed to ripen for 7 days at which time they were removed for further analysis.

Texture

Three fruit were randomly selected and sliced at right angles to the central axis with a parallel bladed knife. A 100 gram sample of one fourth inch slices selected from only the equatorial area was then placed with the slice at right angles to the grid cell of a Kramer shear press equipped with the 2500 pound proving ring and operated at the 10 percent range. Three readings were taken from different samples of the resistance of the flesh to shear forces, giving a measure of the firmness or texture of the tomato flesh (160).

Color

According to the methods used by Hall (68) and McCollum (108), equal and opposite quarter sections were obtained for testing by cutting parallel to the central axis in two planes, 90° opposed. Thus only one half of the fruit was used in analysis. The locular jell and seeds were separated from the pericarp and independent analysis was conducted on each sample (see Figure 1). Each sample was homogenized in a blender for 1 minute at low speed and filtered through a single layer of cheese cloth. One hundred milliliter aliquots were taken from each filtrate. Approximately 0.1 milliliter antifoaming agent (Dowfoam) was then added to the aliquots which were evacuated for 20 minutes. The a/b color ratio was then determined through the use of a Hunter color-difference meter (145).

Soluble solids

The remaining cheese cloth filtrate was then filtered through commercial paper towels cut to fit Buchner funnels. The filtrate was frozen for later analysis. Upon thawing, soluble solids content as percent was measured with a Bauch and Lombe Abbe 13L table model refractometer by placing two drops of the filtrate on the prism and taking the readings. Each reading was duplicated and corrected for temperature variations.

pH and titratable acidity

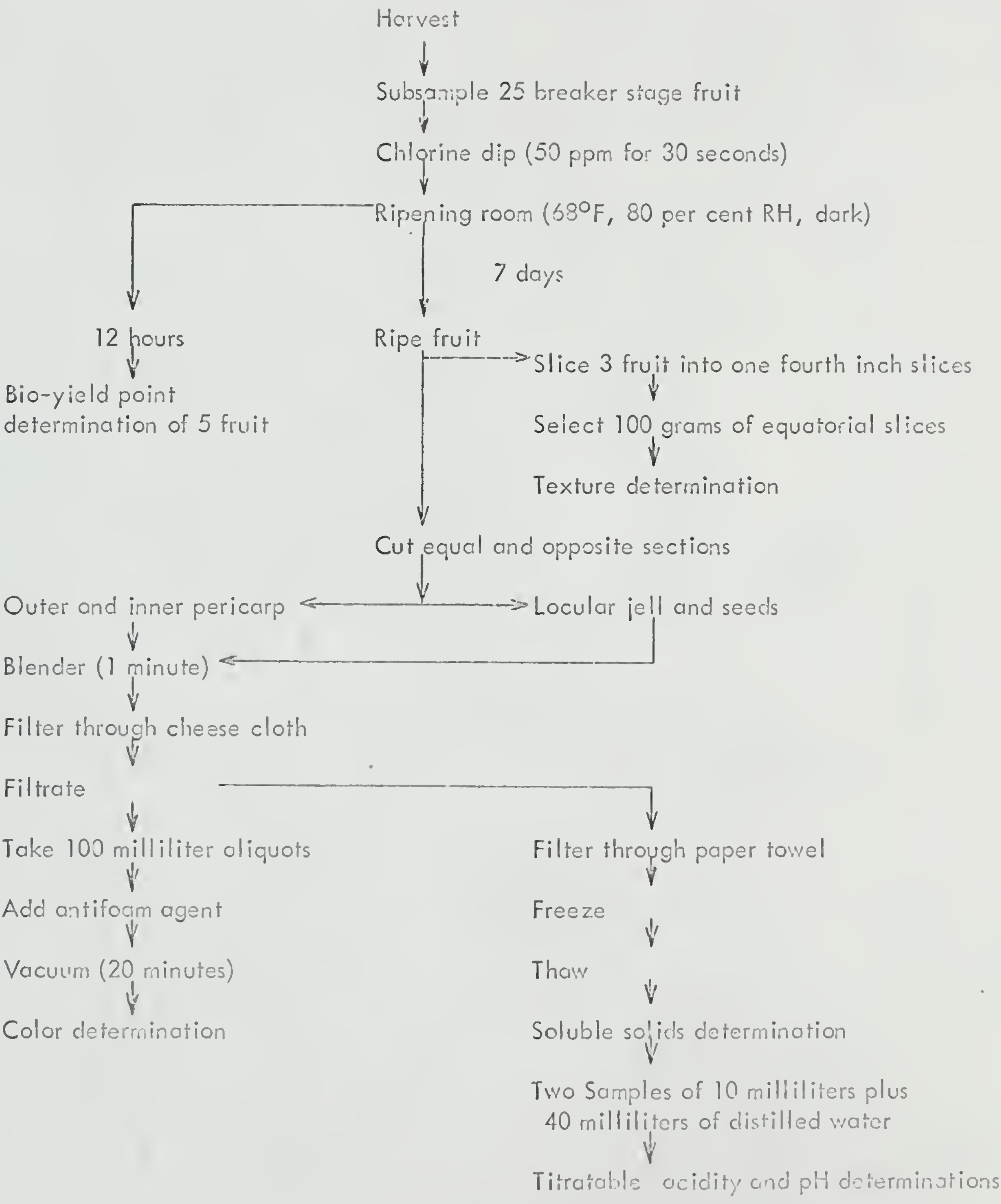
From the thawed samples two 10 milliliter aliquots were diluted with 40 milliliters of distilled water and pH determinations were made with a Fisher pH meter. The samples were then titrated to a pH of 8.0 with 0.1N NaOH on a Fisher titrimeter (71).

Statistical Evaluation

The yield results for each category and total as raw data and as percent of the overall treatment totals and the results from all quality evaluations were analysed with a one-way analysis of variance and individual mean differences were determined with the Duncan's Multiple range test.

Figure 1

SCHEME OF ANALYSIS USED IN EVALUATING THE QUALITY OF FRUIT OBTAINED IN THE SPRING 1969 EXPERIMENT


Harvest
Subsample 25 breaker stage fruit
Chlorine dip (50 ppm for 30 seconds)
Ripening room (68°F, 80 per cent RH, dark)
7 days
12 hours
Ripe fruit
Slice 3 fruit into one fourth inch slices
Bio-yield point determination of 5 fruit
Select 100 grams of equatorial slices
Texture determination
Cut equal and opposite sections
Outer and inner pericarp
Locular jell and seeds
Blender (1 minute)
Filter through cheese cloth
Filtrate
Take 100 milliliter aliquots
Filter through paper towel
Add antifoam agent
Freeze
Vacuum (20 minutes)
Thaw
Color determination
Soluble solids determination
Two Samples of 10 milliliters plus 40 milliliters of distilled water
Titratable acidity and pH determinations

Fall 1969

Field Plots

Plants of the variety Tropi-Gro were transplanted into the field at the Horticultural Unit on August 21. The transplanting was done by hand using plants grown in peat pots filled with commercial potting mix. The sail type was an Arredondo fine sand with a pH of about 5.5-6.0. The row spacing and plant density were as in the spring and the rows were again covered with a black polyethylene mulch. Fertilization, insect and disease control and irrigation were also carried out as in the spring 1969 experiment. Treatments were made as before with the hand carried pneumatic sprayer on triplicate 30 feet long plots under a completely random design.

The chemicals used, their concentrations and times of application appear in Table 3. The times of application were as defined in the previous experiment. The rates of boric acid and Ethrel were reduced somewhat in order to determine if less material could be used with the same results.

On November 17, following a killing frost, all fruit were harvested and sorted into the following categories:

1. Immature green
2. Mature green
3. Breaker and pink
4. Light red and ripe

Since a Chi-square test of the results of the spring experiment in the classes of breaker and pink showed no difference in variance and thus that the two populations were the same, these two categories were combined in this experiment. The weights were taken from each class and the fruit was discarded due to frost damage.

Table 3

CHEMICALS, CONCENTRATIONS AND TIMES OF APPLICATION USED IN THE FALL 1969 EXPERIMENT

First Bloom	Second Bloom	Third Bloom
TIBA (15 ppm)* +		
TIBA (15 ppm)	Boric Acid (10 ppm)*	
TIBA (15 ppm)		Ethrel (1,000 ppm)**

* Weight by Volume determination

** Volume by Volume determination

+ Solutions prepared by disolving 15 milligrams TIBA in 15 milliliters of 95 percent ethyl alcohol and bringing to 1 liter volume with tap water

Quality Evaluation

The fruit were compared only by observation for any abnormalities that could have been caused by the chemical treatments. No other evaluation was made due to the fact that not enough undamaged fruit were available for valid comparison.

Statistical Evaluation

Yield data for each category and total were analysed according to the analysis of variance, and differences between the means of classes within treatments were compared with the Duncan's Multiple range test.

Bioassay of Auxins in the Fruit

In order to investigate the auxin-ethylene relationship further, an experiment was conducted to isolate and compare by the Avena coleoptile straight growth test the auxins produced in tomato fruit over time with and without treatment by 400 ppm Ethrel.

Experimental procedure

Forty mature green tomato fruit of uniform size and appearance were chosen from the guard rows of the fall 1969 experimental plot. After the usual 50 ppm chlorine dip, 15 fruit were treated by a 30 second dip in 400 ppm Ethrel (the concentration was reduced from that used in the field experiment because it was felt that under these conditions the field rate would be excessive). All fruit were then placed under standard ripening conditions. After an initial extraction, samples of five fruit each were selected at one week intervals for four weeks and the indole auxin components were isolated for assay with the Avena straight growth test.

Isolation technique

The technique used for extracting the indole auxins was a modification of the ethyl alcohol extraction procedure presented by Viitos and Meudt (166). The juice of whole fruit was expressed by a hand press through cheese cloth into a sufficient volume of 95 percent ethyl alcohol to produce a final concentration of 80 percent alcohol. This solution was then filtered through Whatman number 5 filter paper in a Buchner funnel. The filtrate was evaporated to dryness. The residue was then redissolved in 100 milliliters of acetonitrile (an indole ring solvent) and this solution was washed three times in a separatory funnel with hexane which was discarded. The acetonitrile fraction was then evaporated and the residue dissolved in 2 milliliters of 100 percent isopropyl alcohol. This fraction was stored in brown glass at 40°F until thin layer chromatographic plating could be done. The plating was done by spotting 50 microliters of the propanol fraction onto Avicel coated thin layer plates and developed for 5 hours in 80 percent propanol. The Rf value was determined with a 10^{-3} Molar standard of IAA and locating the spot with a 50:1 mixture of 5 percent perchloric acid and 0.5 M ferric chloride. After drying, five hundredths of a gram sample of the thin layer material from the Rf area was scraped off and dissolved in the Avena coleoptile test buffer.

Bioassay

A typical Avena straight growth test for auxin activity as described by Leopold (97) was then conducted. The results were analysed using the t statistic (117) to test for an increase in coleoptile length for the extracts from treated and untreated samples.

Spring 1970

Harvest Method Comparison

In order to economically compare hand harvest with machine harvest and machine harvest of chemically treated fruit, a mixed integer programming model (66) was devised with the help of Dr. M. R. Langham, Department of Agricultural Economics, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

The purpose of this model was to evaluate the economic significance of the data obtained in the previous experiments and to provide the grower with an aid in their tomato harvest decisions. The model was designed to compare the variable costs per acre of each harvest method plus the fixed cost per year required if a mechanical harvester was purchased, the unit yield from all of the methods and the price per unit. The limits placed on the model were yield from each method, labor available and acres available.

Statement of the model

The goal of the model was to maximize the following, linear, revenue function (Z).

$$Z = a_1X_1 - a_2X_2 - a_3X_3 - FC(Q) + PX_4$$

Where:

a_1 = variable cost per acre for hand harvest method

X_1 = number of acres to be hand harvested

a_2 = variable cost per acre for machine harvest method

X_2 = number of acres to be machine harvested

a_3 = variable cost per acre for machine harvest method and chemical treatment

X_3 = number of acres to be machine harvested and chemically treated

FC = fixed cost per year of machinery

Q = a variable which takes on the value 0 or 1

P = price per 40 pound crate

X_4 = amount sold, in 40 pound crates, from the 3 methods

Certain assumptions were made regarding the above function and are as follows:

1. The variable cost functions are linear over the range of values considered.
2. There are no other sources of revenue.
3. Only field costs are pertinent and shed and shipping costs need not be considered.
4. All of the yield is sold at the same price.

Certain restraints were placed on the revenue (objective) function. The first of these provided that the sum of the acres used for all methods could not exceed a designated maximum.

$$X_1 + X_2 + X_3 + X_5 = A$$

$$X_2 \qquad -A(Q)\ \text{LE}^{*}\ \ 0$$

$$X_3 \qquad -A(Q)\ \text{LE}\ \ 0$$

$$Q\ \ \text{LE}\ \ 1$$

$$Q\ \ \text{GE}^{**}\ 0$$

$$Q\ \ \text{aninteger}$$

*Less than or equal to

**Greater than or equal to

Where:

A = maximum acres available for cultivation

X_5 - "slack" or unused acres

It can be seen that the first two restraints containing the Q term will never be effective but they require that Q be nonzero if either or both X_2 and X_3 are nonzero, and since Q was restricted to be an integer, if either or both X_2 or X_3 were positive, Q would take on the value 1 and assure that the fixed charge (FC) was incurred.

A balanced equation required that the amount produced must equal the amount sold.

$$Y_1X_1 + Y_2X_2 + Y_3X_3 = X_4$$

Where:

Y_1 = yield (40 pound crates) expected per acre from hand harvest

Y_2 = yield (40 pound crates) expected per acre from machine harvest

Y_3 = yield (40 pound crates) expected per acre from machine harvest of chemically treated fruit.

Finally a labor restriction was placed on the objective function. This restriction required that the sum of the man-hours of labor used in each method could not exceed a maximum amount available.

$$L_1X_1 + L_2X_2 + L_3X_3 + X_6 = SL$$

Where:

L_1 = labor (man-hours) required per acre for hand harvest

L_2 = labor (man-hours) required per acre for machine harvest

L_3 = labor (man-hours) required per acre for machine harvest of chemically treated fruit

X_6 = "slack" or unused labor

SL = maximum labor (man-hours) available

The objective function and restraints are arranged in a tableau in Table 4.

Table 4

SCHEMATIC TABLEAU OF A MIXED INTEGER PROGRAMMING MODEL FOR EVALUATION OF THREE TOMATO HARVESTING METHODS*

	Variables								
	Harvest Methods			Amount sold	Slack				
Equation	Hand X_1	Machine X_2 acres	Machine plus treatment X_3	X_4 40# crates	Land X_5 acres	Labor X_6 man-hours	Zero-One Variable Q**	Type of Restraint	Level of Restraint
Acreage	1	1	1		1			=	A
Yield	Y_1	Y_2	Y_3	-1				=	
Labor	L_1	L_2	L_3			1		=	SL
Fixed Charge		1					-A	LE***	
Fixed Charge			1				-A	LE	
Upper Bound							1	LE	1
Lower Bound							1	GE****	
Objective Function	$-a_1$	$-a_2$	$-a_3$	P			-FC	=	Z (to be maximized)

* Blank cells represent zero coefficients

** Q is further restricted to be an integer, zero or one

*** Less than or equal to

**** Greater than or equal to

Generation of parameters

Costs

The variable cost per acre for hand harvest was taken as the 1968-1969 picking expense for growers in the Immokalee-Lee area of Florida (57). This figure, $218.13, is representative of harvest costs for ground-grown, mature green tomatoes in Florida. The costs for machine harvest had to be interpolated from California data (128). Using the hourly requirements for machine harvest of tomatoes in California and labor costs for Florida (29) of $2.50 per hour for supervisors, $2.00 per hour for harvester operator, $1.30 per hour for sorters, $1.65 per hour for trailer drivers and fork lift operators, $2.00 per hour for miscellaneous labor and a $21.92 per acre machine cost, a per acre variable cost of $114.64 was obtained. The variable cost per acre for the machine harvest of chemically treated tomatoes included the above cost plus an arbitrary $15.00 per acre material cost and a $3.03 per acre application cost (three-fourths of an hour per acre at $1.65 per hour for labor and $1.80 per acre for equipment) (26) for using some type of chemical treatment. The fixed cost per year of machine harvesting was taken as $6,574.00 (128) and no fixed costs were assigned to hand harvest methods.

Price

The initial price used was $2.50 per 40 pound crate but this was to be increased in $.25 steps to $5.00 per crate.

Acreage

An initial limit of 50 acres was set to be later varied at 25 acre intervals to 4,000 acres.

Yields

Using the 1968-1969 yield average from the Immokalee-Lee area as a basis (28), experimental yields were converted to compare to a normal yield. Thus Y_1 and Y_2 were obtained by multiplying the expected hand harvest yield (Y_1 = 264 40 pound crates) for the Immokalee-Lee area by the percent of normal yield obtained from treating the spring 1969 experimental yields as a once-over harvest and eliminating the light red through ripe category of the first harvest and the immature category of the second harvest.

Labor

The labor requirements used for hand harvest were 117.9 man-hours per acre (28); 57.93 man-hours for machine harvest and 58.68 man-hours for machine harvest and chemical treatment (128). A total available labor limit was arbitrarily set at 3,500 man-hours but was to be varied at 300 man-hour intervals to a maximum of 20,000 man-hours.

Solution

The assembled data were then transferred to a Hollerith card data deck for submission to the International Business Machine Model 360 computer at the Computing Center, University of Florida, for solution under the Mathematical Programming System (MPS) 360 control program (115).

Parametric programming

The sub-routines available within the MPS 360 program that allowed the parameters (coefficients and restraints) to be varied in discreet steps were utilized to evaluate the sensitivity of the model (72, 115). The parameters which were of doubtful accuracy or validity that were varied were the variable cost of the machine harvest of chemically treated fruit, price, acreage restraints, yields from both mechanical harvesting methods and labor restraints.

RESULTS

Fall 1968

Foliar Symptoms

The only foliar symptom noted was some leaf roll in the early IAA treatments, especially at 30 ppm.

Yield Data

Single harvest

Light red and ripe fruit

The effects of the treatments on the single yield of light red and ripe fruit are presented in Table 5. It is evident from the data that the later applications of Duraset at 100 ppm and Fatty Acid Ester at 1.5 percent gave the highest yield of ripe fruit. Also higher than control yields were obtained with both applications of IAA at 10 ppm, Emery C-9 at 1.5 percent and Ethrel at 600 ppm applied at the second bloom.

Immature, mature green through pink fruit and total yield

There was no significant difference between the single harvest yields of any treatment on immature, mature green through pink fruit or total yield (see Table 6).

Table 5

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE NUMBER OF LIGHT RED AND RIPE FRUIT PER PLOT, FALL 1968

		Time of Application	
		First Bloom (2 weeks after transplant)	Second Bloom (4 weeks after transplant)
Chemical	Concentration	Number	
Duraset	100 ppm	5.6 fgh*	21.6 a*
Duraset	300 ppm	6.3 efgh	9.6 bcdefg
Emery C-9	0.5 %	4.6 gh	8.0 defgh
Emery C-9	1.5 %	13.0 bcde	20.0 ab
Ethrel	200 ppm	4.6 gh	9.3 cdefg
Ethrel	600 ppm	1.6 h	12.0 cdef
F. A. Ester	0.5 %	1.3 h	3.0 gh
F. A. Ester	1.5 %	5.6 fgh	21.0 a
IAA	10 ppm	16.0 abc	15.3 abcd
IAA	30 ppm	7.3 efgh	7.3 efgh
None		4.3 gh	

*Those numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 6

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE NUMBER OF IMMATURE, MATURE GREEN THROUGH PINK AND TOTAL FRUIT PER PLOT*

FALL 1968

		Time of Application					
		First Bloom			Second Bloom		
		Immature	MG--pink	Total	Immature	MG--pink	Total
Chemical	Concentration			Number			
Duraset	100 ppm	103.0	55.6	164.3	80.0	65.3	182.6
Duraset	300 ppm	90.6	57.0	154.0	99.6	77.6	231.3
Emery C-9	0.5 %	99.3	55.3	159.3	119.9	68.3	189.6
Emery C-9	1.5 %	123.0	72.6	207.6	121.0	75.0	216.0
Ethrel	200 ppm	129.6	70.3	224.6	55.0	31.6	96.0
Ethrel	600 ppm	79.3	32.3	113.3	73.0	39.3	124.3
F. A. Ester	0.5 %	99.6	53.6	154.6	132.6	67.0	203.3
F. A. Ester	1.5 %	115.3	84.6	205.6	124.0	96.0	241.0
IAA	10 ppm	113.3	81.0	210.3	148.6	89.0	253.0
IAA	30 ppm	117.6	54.6	179.6	103.6	64.6	208.3
		Immature	MG--pink	Total			
None		121.3	62.0	187.6			

*A one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Quality Evaluation

Ripening characteristics

No externally evident differences were noted in the mature green fruit as they ripened; however, the later Ethrel applications were fully ripe one to two days earlier than the other treatments. Increasing the Ethrel concentration from 200 ppm to 600 ppm increased the early ripening tendency.

Handling characteristics

The IAA and second bloom Duraset treated fruit showed a tendency to break down more rapidly as was evidenced by an increased amount of bacterial soft rot in these fruit. Some parthenocarpy was noted in the IAA treatments.

Spring 1969

Foliar Symptoms

The Ethrel treatments were the only ones showing definite foliar symptoms. These symptoms were epinasty, increased formation of adventitious roots and an early tendency for the vines to lose their bush-like appearance and become prostrate. Some blossom drop was apparent. The foliar symptoms were not permanent and new growth was unaffected, the plants treated at the third bloom having lost all symptoms by harvest.

Yield Data

First harvest

Light red and ripe fruit

The effect of the chemical, concentration and time of application on the yield of light red and ripe fruit appears in Table 7. Here it is shown that the greatest

Table 7

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF LIGHT RED AND RIPE FRUIT PER PLOT--FIRST HARVEST SPRING 1969

Time of Application and Chemical				Average Yield +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Per Cent of Total
Duraset*				5.33 d	2.88 de
Duraset		Ethrel**		7.96 cd	4.45 cde
Duraset	Boric Acid***			3.43 d	2.00 e
Duraset	Boric Acid	Ethrel		13.83 b	7.93 b
	Boric Acid	Ethrel		12.13 bc	7.73 bc
		Ethrel		5.60 d	3.56 de
			Ethrel	19.80 a	12.33 a
	Boric Acid			5.40 d	2.38 de
	Calcium Chloride***			5.46 d	3.15 de
	Boric Acid Plus Calcium Chloride			8.86 bcd	5.50 bcd
Control				4.96 d	2.84 de

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

effect on the early yield of these fruit was produced by the later Ethrel application. The absolute yield (expressed as pounds) and relative yield (expressed as percent of the grand total of the various classes and harvests within the treatments) were both much higher than the control. Similar, though not as extensive, effects were also shown by the Duraset-boric acid-Ethrel combination and the boric acid-Ethrel combination. Finally, the Duraset-Ethrel treatment produced a higher absolute yield the the control but did not demonstrate a significantly different relative yield.

In addition, the gibberellic acid and ascorbic acid treatments, applied at third bloom plus one week, produced yields of 4. 17 pounds and 6.55 pounds, respectively. Since these trials were not replicated, they cannot be compared directly with the other treatments but the yields are comparable with treatments that did not differ significantly from the control.

Breaker through pink fruit

Although the raw data were taken on the two separate classes of fruit, breaker and pink, a Chi-square test (117) of the replicate totals of both classes showed no difference between the two populations, indicating that the sorting procedure for separating these two classes was not valid. Thus the two categories were combined for treatment comparison and the results appear in Table 8.

When expressed as absolute yields, the only treatment significantly higher than the control was the boric acid-Ethrel combination. However, a reduction in yield is seen with the Duraset-Ethrel and boric acid plus calcium chloride treatments.

The relative yields still show the boric acid-Ethrel combination to be higher than control but the later application of Ethrel also produced a higher percent of breaker through pink fruit in the first harvest. No treatments show a relative yield lower than the control.

Table 8

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF BREAKER THROUGH PINK FRUIT PER PLOT--COMBINED DATA--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				16.60 c	9.37 c
Duraset		Ethrel**		19.80 bc	11.23 bc
Duraset	Boric Acid***			17.30 bc	10.46 c
Duraset	Boric Acid	Ethrel		20.73 abc	12.21 bc
	Boric Acid	Ethrel		27.13 a	17.40 a
		Ethrel		15.93 c	11.60 bc
			Ethrel	24.30 ab	15.13 ab
	Boric Acid			18.93 b	8.65 c
	Calcium Chloride***			17.36 bc	10.51 c
	Boric Acid Plus Calcium Chloride			16.36 c	10.11 c
Control				17.97 b	10.15 c

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

The gibberellic acid and ascorbic acid treatments yielded 15.45 pounds and 8.58 pounds as an absolute yield, and it appears that the ascorbic acid treatment would be significantly lower than control, but since these are only observations, no definite conclusions can be drawn.

Subtotal

Many of the same effects produced by chemical, concentration and time of application appear in the first harvest total yield, Table 9, as are seen in the ripe and breaker through pink yields. The highest early total yields were the result of the later Ethrel treatment, the Duraset-boric acid-Ethrel combination and the boric acid-Ethrel combination. Also significantly higher than control yields were obtained by the Duraset-Ethrel treatment, the early application of Ethrel, the boric acid treatment and the boric acid plus calcium chloride treatment.

When converted to percent of treatment totals, however, some of the increased early yield is not as evident. The late application of Ethrel still produced the highest relative yield, followed by the boric acid-Ethrel combination. The Duraset-boric acid-Ethrel combination was the only other treatment that produced a yield significantly greater than the control.

Second harvest

Light red and ripe fruit

The only treatment that showed a significantly greater absolute yield of light red and ripe fruit is boric acid alone (Table 10). Although not significant, the much higher yields of Duraset-boric acid-Ethrel, boric acid-Ethrel, early Ethrel and calcium chloride treatments could prove to be of importance in later trials. One treatment, Duraset-Ethrel, showed a significantly lower yield.

An interesting shift in significance became apparent upon conversion to percent.

Table 9

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF TREATMENT ON THE AVERAGE TOTAL YIELD OF FRUIT PER PLOT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield †	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				21.96 d	12.26 e
Duraset		Ethrel**		27.70 c	15.69 cde
Duraset	Boric Acid***			20.76 d	12.46 de
Duraset	Boric Acid	Ethrel		34.56 abc	20.15 bc
	Boric Acid	Ethrel		39.26 ab	25.14 ab
		Ethrel		28.90 bc	17.83 cd
			Ethrel	44.16 a	27.47 a
	Boric Acid			24.33 c	11.05 e
	Calcium Chloride***			22.83 d	13.00 de
	Boric Acid Plus Calcium Chloride			25.23 c	15.62 cde
Control				22.93 d	13.00 de

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 10

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF LIGHT RED AND RIPE FRUIT PER PLOT-- SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield †	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				34.33 b	19.24 abc
Duraset		Ehtrel**		23.00 c	13.28 c
Duraset	Boric Acid***			31.06 b	17.02 abc
Duraset	Boric Acid	Ethrel		38.30 ab	22.46 abc
	Boric Acid	Ethrel		44.76 ab	28.14 a
		Ethrel		40.76 ab	25.38 ab
			Ethrel	30.96 b	19.04 abc
	Boric Acid			59.33 a	26.33 ab
	Calcium Chloride***			46.93 ab	26.27 ab
	Boric Acid Plus Calcium Chloride			34.30 b	21.35 abc
Control				26.60 b	16.67 bc

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

The highest relative yield was that of the boric acid-Ethrel combination. No other treatment was significantly greater than the control on a percent basis.

The gibberellic acid trial produced a yield of light red and ripe fruit of 44.88 pounds and the ascorbic acid trial produced a yield of 35.16 pounds, and apparently neither of which was significantly different from the control.

Breaker through pink fruit

The data for this category were originally taken as two separate classes. However, as in the data for the first harvest, no significant difference was found between the classes, thus the data were combined for analysis and appear in Table 11. A Chi-square test for population differences between the breaker, pink and mature green classes was significant; therefore, these classes could not be combined.

As can be seen in Table 11 the only treatment to produce an absolute yield greater than the control was the boric acid treatment. There were no differences evident in the relative yields of any treatment.

The yields of the gibberellic acid and ascorbic acid trials, 56.99 pounds and 40.66 pounds respectively, were again not apparently significant although the ascorbic acid yield was lower than the control.

Mature green fruit

In this category, the boric acid treatment is seen (Table 12) to be the one that resulted in a significantly higher than control absolute yield. On the other hand, several treatments reduced the yield of mature green fruit. The boric acid-Ethrel, early and late Ethrel and boric acid plus calcium chloride treatments all showed significantly lower yields.

In reference to relative yields, it is seen that the control, Duraset-Ethrel and

Table 11

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF BREAKER THROUGH PINK FRUIT PER PLOT--COMBINED DATA--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds †	Percent of Total ††
Duraset*				59.70 ab	34.47
Duraset		Ethrel**		52.40 abc	29.99
Duraset	Boric Acid***			49.70 bc	29.30
Duraset	Boric Acid	Ethrel		48.40 bc	28.23
	Boric Acid	Ethrel		43.80 c	28.04
		Ethrel		51.26 abc	31.77
			Ethrel	45.23 c	28.05
	Boric Acid			63.46 a	28.69
	Calcium Chloride***			50.50 bc	28.24
	Boric Acid Plus Calcium Chloride			55.36 abc	34.09
Control				51.46 abc	29.81

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

†† The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Table 12

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF MATURE GREEN FRUIT PER PLOT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				38.40 abcd	21.27 ab
Duraset		Ethrel**		50.13 ab	28.35 a
Duraset	Boric Acid***			48.30 ab	28.45 a
Duraset	Boric Acid	Ethrel		36.13 abcd	20.51 ab
	Boric Acid	Ethrel		18.26 d	11.20 c
		Ethrel		26.83 cd	16.54 bc
			Ethrel	28.50 cd	17.74 bc
	Boric Acid			55.16 a	24.68 ab
	Calcium Chloride***			40.03 abc	21.87 ab
	Boric Acid Plus Calcium Chloride			30.46 bcd	18.62 bc
Control				47.36 ab	27.67 a

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Duraset-boric acid produced the highest percent of mature green fruit in the second harvest. Also not significantly different from the control were the Duraset, Duraset-boric acid-Ethrel, boric acid and calcium chloride treatments. The remainder of treatments were lower than the control.

The gibberellic acid and ascorbic acid trials followed much the same pattern as before. The gibberellic acid yield, 39.38 pounds, did not appear significantly different while the ascorbic acid yield, 20.48 pounds, did not seem to be lower than the control.

Immature fruit

There was no effect from any of the treatments on either the absolute or relative yield of immature fruit as can be seen in Table 13.

The gibberellic acid, 25.74 pounds, and oscorbic acid, 16.20 pounds, yields also did not seem to be significant.

Subtotal

The one treatment that resulted in an increase in the absolute total yield of the second harvest is evident in Table 14 as the boric acid treatment. No other treatment differed significantly from the control.

Upon conversion to percent, the increased yield of the boric acid treatment was no longer evident. In relation to relative yield, the only significant effects were those lower than control. The early and late applications of Ethrel, the Duraset-boric acid-Ethrel combination and the boric acid-Ethrel combinations showed reduced yields. Duraset, Duraset-Ethrel, Duraset-boric acid, boric acid, calcium chloride and boric acid plus calcium chloride treatments did not differ from the control.

Table 13

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE YIELD OF IMMATURE FRUIT PER PLOT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield+	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				22.56	12.77
Duraset		Ethrel**		22.90	12.68
Duraset	Boric Acid***			19.30	12.73
Duraset	Boric Acid	Ethrel		15.23	8.61
	Boric Acid	Ethrel		11.73	7.45
		Ethrel		13.66	8.46
			Ethrel	12.16	7.69
	Boric Acid			20.53	9.11
	Calcium Chloride***			20.10	10.61
	Boric Acid Plus Calcium Chloride			16.93	10.25
Control				22.45	12.89

* 200 ppm

**1,250 ppm

*** 20 ppm

+The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Table 14

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE TOTAL YIELD OF FRUIT PER PLOT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Average Yield +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Pounds	Percent of Total
Duraset*				155.00 ab	87.74 a
Duraset		Ethrel**		148.43 b	84.30 ab
Duraset	Boric Acid***			150.03 b	87.53 a
Duraset	Boric Acid	Ethrel		138.06 b	79.85 b
	Boric Acid	Ethrel		118.16 b	74.85 bcd
		Ethrel		132.53 b	82.16 b
			Ethrel	116.86 b	72.53 d
	Boric Acid			198.50 a	88.95 a
	Calcium Chloride***			157.06 ab	86.99 a
	Boric Acid Plus Calcium Chloride			137.06 b	84.37 ab
Control				149.63 b	88.65 a

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Grand total

No significant difference was found due to any of the treatments on the grand total as is shown in Table 15.

Quality Evaluation

Bio-yield point

First harvest

The effect of chemical, concentration and time of application on the average bio-yield point of chamber ripened fruit from the first harvest is shown in Table 16. The only significantly different treatment was that of the gibberellic acid. This treatment shows a much more firm fruit than the others.

The skin strength measures proved to have too great a variation, ranging from 2.9 to 8.0 pounds in the same replicates. It is felt a much larger sample would be required to show significant differences,and there may be some question as to this being a valid measure of skin strength since there was difficulty in removing a uniform layer of skin.

Second harvest

No differences were found among the treatments in the second harvest (Table 17) and since there was not enough fruit from the gibberellic acid and ascorbic acid treatments for a complete quality analysis, these treatments were left out of this particular test.

Shear force

First harvest

The effect of chemical, concentration and time of application on the average

Table 15

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE TOTAL YIELD OF TWO HARVESTS--COMBINED DATA, SPRING 1969

Time of Application and Chemical				
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Average Yield (pounds) +
Duraset*				176.96
Duraset		Ethrel**		176.13
Duraset	Boric Acid***			170.79
Duraset	Boric Acid	Ethrel		172.62
	Boric Acid	Ethrel		157.42
		Ethrel		161.43
			Ethrel	161.02
	Boric Acid			222.83
	Calcium Chloride***			179.89
	Boric Acid Plus Calcium Chloride			169.29
Control				172.56

* 200 ppm

**1,250 ppm

*** 20 ppm

+ The one-way analysis of variance was unable to detect a significant difference at the 5 percent level.

Table 16

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE BIO-YIELD POINT OF WHOLE BREAKER FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Bio-Yield Point (pounds) +
Duraset*				7.56 bc
Duraset		Ethrel**		7.70 bc
Duraset	Boric Acid***			8.33 bc
Duraset	Boric Acid	Ethrel		7.16 bc
	Boric Acid	Ethrel		6.96 bc
		Ethrel		5.63 bc
			Ethrel	6.30 bc
	Boric Acid			6.00 bc
	Calcium Chloride***			6.16 bc
	Boric Acid Plus Calcium Chloride			5.26 c
			GA_3 (35 ppm)	14.60 a
			Ascorbic Acid (10,000 ppm)	8.86 b
Control				6.30 bc

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 17

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE BIO-YIELD POINT OF WHOLE BREAKER FRUIT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Bio-Yield Point (pounds) †
Duraset*				6.50
Duraset		Ethrel**		7.46
Duraset	Boric Acid***			6.80
Duraset	Boric Acid	Ethrel		8.30
	Boric Acid	Ethrel		7.73
		Ethrel		6.46
			Ethrel	8.10
	Boric Acid			8.06
	Calcium Chloride***			8.00
	Boric Acid Plus Calcium Chloride			9.43
Control				8.16

* 200 ppm

**1,250 ppm

*** 20 ppm

† The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

force required to shear a 100 gram sample of slices taken from chamber ripened fruit of the first harvest is shown in Table 18. Here it can be seen that the single Duraset treatment shows a significant difference from the control although the Duraset-boric acid and Duraset-boric acid-Ethrel treated fruit have higher values.

In the evaluation of the Ethrel treated fruit, care was taken to avoid the ones that were beyond the stage comparable with the other treatments.

The gibberellic acid and ascorbic acid treated fruit were not compared in this analysis due to there not being enough fruit available for adequate replication. However, the measurements made, 112.5 pounds and 102.5 pounds for the gibberellic acid and ascorbic acid respectively, compared with those treatments that were higher but not significantly different.

Second harvest

The same pattern appears in this test as is seen in the previous one (see Table 19). The data show only the Duraset treatment produced significantly firmer fruit.

Enough of the gibberellic acid and ascorbic acid treated fruits were available to provide adequate replication and,as is evident in the table, they did not differ significantly from the control.

Color

First harvest

No difference in the color of the fruits from the various treatments as represented by the a/b ratio was evident. The data are presented in Table 20. Although no statistical comparison was made, the pericarp fraction appeared to have a generally higher a/b ratio than the locule.

Table 18

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE FORCE REQUIRED TO SHEAR 100 GRAMS OF EQUATORIAL SLICES TAKEN FROM CHAMBER RIPENED FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Shear Force (pounds) +
Duraset*				131.6 a
Duraset		Ethrel**		91.6 b
Duraset	Boric Acid***			110.0 ab
Duraset	Boric Acid	Ethrel		112.5 ab
	Boric Acid	Ethrel		101.6 b
		Ethrel		97.5 b
			Ethrel	97.5 b
	Boric Acid			95.0 b
	Calcium Chloride***			90.0 b
	Boric Acid Plus Calcium Chloride			95.8 b
Control				95.8 b

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 19

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE FORCE REQUIRED TO SHEAR 100 GRAMS OF EQUATORIAL SLICES TAKEN FROM CHAMBER RIPENED FRUIT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Shear Force (pounds) †
Duraset*				112.5 a
Duraset		Ethrel**		98.3 abcd
Duraset	Boric Acid***			99.1 abcd
Duraset	Boric Acid	Ethrel		107.5 ab
	Boric Acid	Ethrel		69.1 d
		Ethrel		79.1 abcd
			Ethrel	73.3 d
	Boric Acid			77.5 bcd
	Calcium Chloride***			105.0 abc
	Boric Acid Plus Calcium Chloride			73.3 cd
			GA_3 (35 ppm)	79.1 abcd
			Ascorbic Acid (10,000 ppm)	106.6 ab
Control				95.0 abcd

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 20

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE a/b COLOR RATIO OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				a/b Ratio †	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				1.50	2.78
Duraset		Ethrel**		1.42	2.22
Duraset	Boric Acid***			1.16	1.96
Duraset	Boric Acid	Ethrel		1.31	2.11
	Boric Acid	Ethrel		1.07	2.22
		Ethrel		1.10	1.83
			Ethrel	1.18	1.92
	Boric Acid			1.15	1.98
	Calcium Chloride***			1.02	1.81
	Boric Acid Plus Calcium Chloride			1.27	1.74
			GA_3 (35 ppm)	1.33	2.22
			Ascorbic Acid (10,000 ppm)	1.22	2.04
Control				1.28	2.19

* 200 ppm

**1,250 ppm

*** 20 ppm

† The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Second harvest

Similar to the first harvest, the second harvest showed no difference in color as a result of the treatments (see Table 21). Here the higher a/b ratio of the pericarp was even more marked.

Soluble solids

The effect of chemical, concentration and time of application on the average soluble solids content of the locular and pericarp fractions of chamber ripened fruit from the first and second harvests is presented in Tables 22 and 23.

First harvest

Locule.-- As presented in Table 22, the highest soluble solids content of the locular area was the result of the later application of Ethrel. The next highest percent soluble solids was produced by the boric acid-Ethrel and Duraset-boric acid-Ethrel combinations. Following this, the Duraset and boric acid treated fruit were still higher in soluble solids than the control. The last treatment to be significantly higher than control is the Duraset-Ethrel combination. Finally, the gibberellic acid and ascorbic acid treatments produced fruit with locular areas that were significantly lower in soluble solids than the control.

Pericarp.-- In this fraction the differences were not quite as marked (see Table 22), although the pericarp area was generally higher in soluble solids than the locular area. Here no treatment was different than the control yet there were differences among the various treatments. The gibberellic acid and Duraset-boric acid treatments were higher than the boric acid-Ethrel, Duraset and Duraset-boric acid-Ethrel treatments.

Table 21

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE a/b COLOR RATIO OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				a/b Ratio †	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				1.20	2.03
Duraset		Ethrel**		1.49	2.17
Duraset	Boric Acid***			1.28	2.37
Duraset	Boric Acid	Ethrel		1.51	2.30
	Boric Acid	Ethrel		1.40	2.05
		Ethrel		1.43	2.45
			Ethrel	1.70	2.74
	Boric Acid			1.70	2.46
	Calcium Chloride***			1.49	2.23
	Boric Acid Plus Calcium Chloride			1.58	2.50
			GA_3 (35 ppm)	1.64	2.13
			Ascorbic Acid (10,000 ppm)	1.57	2.33
Control				1.82	2.41

* 200 ppm

**1,250 ppm

*** 20 ppm

† The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Table 22

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE SOLUBLE SOLIDS CONTENT OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				Soluble Solids (percent) +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				3.62 c	3.85 cd
Duraset		Ethrel**		3.32 de	4.30 abc
Duraset	Boric Acid***			2.02 h	4.50 a
Duraset	Boric Acid	Ethrel		4.02 b	3.70 d
	Boric Acid	Ethrel		4.10 ab	4.00 bcd
		Ethrel		3.42 d	4.17 abcd
			Ethrel	4.25 a	4.37 ab
	Boric Acid			3.50 cd	4.37 ab
	Calcium Chloride***			2.50 h	4.27 abc
	Boric Acid Plus Calcium Chloride			3.17 ef	4.07 abcd
			GA_3 (35 ppm)	2.82 g	4.51 a
			Ascorbic Acid (10,000 ppm)	2.77 g	4.17 abcd
Control				3.07 f	4.07 abcd

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 23

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE SOLUBLE SOLIDS CONTENT OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Soluble Solids (percent) †	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				4.05 g	4.22 e
Duraset		Ethrel**		4.37 bc	4.62 cd
Duraset	Boric Acid***			4.42 b	5.02 ab
Duraset	Boric Acid	Ethrel		4.42 b	5.02 ab
	Boric Acid	Ethrel		4.27 cde	4.62 cd
		Ethrel		4.90 a	5.25 a
			Ethrel	4.25 cde	4.50 cde
	Boric Acid			4.30 bcde	4.70 bcd
	Calcium Chloride***			4.20 ef	4.35 de
	Boric Acid Plus Calcium Chloride			4.10 fg	4.55 cde
			GA_3 (35 ppm)	4.22 def	4.60 cd
			Ascorbic Acid (10,000 ppm)	4.35 bcd	4.85 bc
Control				4.22 def	4.82 bcd

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Second harvest

Locule.-- The pattern of significant differences was not quite the same as in the first harvest. In this harvest, the highest locular soluble solids are apparent in Table 23 as those from fruit treated with Ethrel at the second bloom. Next in soluble solids percent are the Duraset-boric acid, Duraset-boric acid-Ethrel and Duraset-Ethrel treatments. The remaining treatments, except for Duraset, did not vary significantly from the control although the ascorbic acid and boric acid treatments tended to higher soluble solids content. The Duraset treated fruit showed a significantly lower soluble solids content.

Pericarp.-- The same differences existed in the pericarp area as in the locular area (see Table 23), although not as well defined. The early Ethrel treatment is the only treatment that produced significantly higher soluble solids, although the Duraset-boric acid and Duraset-boric acid-Ethrel treatments were considerably higher than the control. As in the locular area, the pericarp area of the Duraset treated fruit was significantly lower in soluble solids.

pH

The effect of chemical, concentration and time of application on the average pH of locular and pericarp fractions of chamber ripened fruit from the first and second harvest is shown in Tables 24 and 25.

First harvest

Locule.-- The effect of chemical, concentration and time of application on the first harvest average locular pH is presented in Table 24. In Table 24 it can be seen that four treatments--Duraset, gibberellic acid, the later application of Ethrel and

Table 24

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE pH OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				pH	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule+	Pericarp++
Duraset*				4.38 a	4.37
Duraset		Ethrel**		4.30 ab	4.31
Duraset	Boric Acid***			4.30 ab	4.30
Duraset	Boric Acid	Ethrel		4.20 c	4.29
	Boric Acid	Ethrel		4.21 c	4.26
		Ethrel		4.29 bc	4.32
			Ethrel	4.37 a	4.28
	Boric Acid			4.12 d	4.23
	Calcium Chloride***			4.27 bc	4.30
	Boric Acid Plus Calcium Chloride			4.28 bc	4.26
			GA_3 (35 ppm)	4.38 a	4.27
			Ascorbic Acid (10,000 ppm)	4.36 a	4.45
Control				4.26 bc	4.26

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

++ The one-way analysis of variance was unable to detect any significant difference at the 5 percent level.

Table 25

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE pH OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT-- SECOND HARVEST, SPRING 1969

Time of Application and Chemical				pH +	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				4.34 de	4.38 abc
Duraset		Ethrel**		4.45 bcd	4.21 bcd
Duraset	Boric Acid***			4.40 de	4.35 abcd
Duraset	Boric Acid	Ethrel		4.44 bcd	4.34 abcd
	Boric Acid	Ethrel		4.55 ab	4.50 a
		Ethrel		4.52 abc	4.43 a
			Ethrel	4.41 cde	4.44 a
	Boric Acid			4.61 a	4.47 a
	Calcium Chloride***			4.20 f	4.17 cd
	Boric Acid Plus Calcium Chloride			4.26 f	4.19 cd
			GA_3 (35 ppm)	4.52 abc	4.41 ab
			Ascorbic Acid (10,000 ppm)	4.45 bcd	4.31 abcd
Control				4.30 ef	4.15 d

* 200 ppm

**1,250 ppm

*** 20 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

ascorbic acid--produced a significantly higher pH of the locular area. Also in this table the significant lowering of the pH by the boric acid application is seen.

Pericarp.-- No significant effect can be seen due to the treatments on the pH of the pericarp area.

Second harvest

Locule.-- An almost complete reversal of the effects noted in the first harvest is seen in Table 25. The boric acid treatment became the one with the highest pH. Also significantly higher were the boric acid-Ethrel, early Ethrel and gibberellic acid applications. Finally, the Duraset-Ethrel, Duraset-boric acid-Ethrel and ascorbic acid treatments had the significantly lowest pH, other than the control.

Pericarp.-- In this case, significant effects among the treatments were noted in the pericarp areas (see Table 25). The boric acid-Ethrel combination, early and late applications of Ethrel and boric acid all showed the highest pH. Others not as high, but significantly higher than control values, were the Duraset and ascorbic acid treatments.

Titratable acidity

The effect of chemical, concentration and time of application on the average titratable acidity of the locular and pericarp portions of chamber ripened fruit from the first and second harvest is presented in Tables 26 and 27.

First harvest

Locule.-- The treatment effects on the titrateable acidity of the locular area are shown in Table 26. Duraset and Duraset-boric acid-Ethrel produced the highest titratable acidity expressed as milliliters of one-tenth Normal sodium hydroxide

Table 26

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE TITRATABLE ACIDITY OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--FIRST HARVEST, SPRING 1969

Time of Application and Chemical				Titratable Acidity † (milliliters of .1 N NaOH)	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				8.65 a	5.20 e
Duraset		Ethrel**		7.15 bc	6.85 a
Duraset	Boric Acid***			4.15 f	5.50 c
	Boric Acid	Ethrel		8.45 a	5.50 c
	Boric Acid	Ethrel		8.20 ab	5.50 c
		Ethrel		7.10 bc	5.20 e
			Ethrel	6.90 cd	5.20 e
	Boric Acid			7.85 abc	5.95 b
	Calcium Chloride***			5.70 de	5.50 c
	Boric Acid Plus Calcium Chloride			7.00 bc	5.80 b
			GA_3 (35 ppm)	4.45 f	5.95 b
			Ascorbic Acid (10,000 ppm)	4.60 e	5.30 d
Control				6.65 cd	5.85 b

* 200 ppm

**1,250 ppm

*** 20 ppm

† Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 27

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE TITRATABLE ACIDITY OF LOCULAR AND PERICARP AREAS OF CHAMBER RIPENED FRUIT--SECOND HARVEST, SPRING 1969

Time of Application and Chemical				Titratable Acidity † (milliliters of .1 N NaOH)	
First Bloom	Second Bloom	Third Bloom	Third Bloom plus 1 week	Locule	Pericarp
Duraset*				6.55 g	4.75 f
Duraset		Ethrel**		9.55 b	7.05 a
Duraset	Boric Acid***			7.70 ef	5.35 e
Duraset	Boric Acid	Ethrel		8.35 d	5.70 cd
	Boric Acid	Ethrel		7.75 e	4.60 g
		Ethrel		8.45 d	5.80 c
			Ethrel	9.27 c	5.65 d
	Boric Acid			7.65 ef	5.80 c
	Calcium Chloride***			8.25 d	5.30 e
	Boric Acid Plus Calcium Chloride			7.50 f	5.60 d
			GA_3 (35 ppm)	8.45 d	4.55 g
			Ascorbic Acid (10,000 ppm)	7.75 e	4.75 f
Control				9.85 a	6.85 b

* 200 ppm

**1,250 ppm

*** 20 ppm

† Number followed by the same letter(s) are not significantly different at the 5 percent level.

required to titrate a given volume of diluted extract to pH 8.0. No other treatments produced a significantly higher titratable acidity but the Duraset-boric acid, gibberellic acid and ascorbic acid treatments significantly reduced the titratable acidity.

Pericarp.-- Although generally lower (see Table 26), the titratable acidity of the pericarp areas from the treated fruit did not parallel that of the locular fraction. Here the highest titratable acidity was produced by the Duraset-Ethrel combination. All other effects were manifested as lower than control titratable acidity. The Duraset treatment and the two Ethrel treatments produced the lowest acidity followed by the ascorbic acid treatment and then the Duraset-boric acid, Duraset-boric acid-Ethrel, boric acid-Ethrel and calcium chloride treatments.

Second harvest

Locule.-- The effects on the locular area of the fruit from this harvest were demonstrated as all treatments producing a lower titratable acidity than the control (see Table 27). The lowest titratable acidity was the result of the Duraset treatment.

Pericarp.-- One treatment, as shown in Table 27, demonstrated an increase over the control. The Duraset-Ethrel combination produced the highest titratable acidity in the pericarp fraction of the fruit in the second harvest. All other treatments reduced the acidity and the gibberellic acid and the boric acid-Ethrel treatments reduced it the most.

Fall 1969

Foliar Symptoms

Severe foliar symptoms were observed with the TIBA applications. These symptoms appeared one to two days following treatment and included crinkled leaf margins stunted plants, delayed flowering and flower bud fasciation. The symptoms began to disappear at about 20 days following treatment; however, the plant size never reached that of the control. The flowering remained delayed, the TIBA treated plants setting the first fruit at the time of anthesis of the second bloom (eighth to ninth internode as defined here) of the control plants. The fasciation was not extreme but it was increased by the TIBA treatment for no fasciated flower buds were found in the control plants.

The boric acid treatments tended to aggravate the TIBA symptoms. The later application of boric acid so enhanced the stunting of the plants that they remained considerably behind the control plants in growth throughout the season.

Ethrel symptoms were as noted in the spring, epinasty and adventitious root formation. The symptoms were not as extensive in this experiment.

Yield Data

Single harvest

Breaker through pink fruit

Table 28, where the effect of chemical, concentration and time of application on the average single harvest yield of breaker through pink fruit is presented, shows that no significant differences exist as a result of the treatments on the single yield of breaker through pink fruit; however, it does indicate that all treatments reduce the yield.

Mature green fruit

It is evident from Table 29 that the yield of mature green fruit was significantly reduced by all treatments and the TIBA-boric acid treatment (the chemicals were applied

Table 28

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE WEIGHT OF BREAKER THROUGH PINK FRUIT PER PLOT--FALL 1969

Time of Application and Chemical			Average Yield (pounds) +
First Bloom	Second Bloom	Third Bloom	
TIBA*			2.26
TIBA plus Boric Acid**			4.06
TIBA	Boric Acid		.13
TIBA		Ethrel***	3.26
Control			8.70

* 15 ppm

** 10 ppm

*** 1,000 ppm

+ The one-way analysis of variance was able to detect a significant difference only at the 10 percent level, thus the Duncan's Multiple range test was not used.

Table 29

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE WEIGHT OF MATURE GREEN FRUIT PER PLOT--FALL, 1969

Time of Application and Chemical			Average Yield (pounds) +
First Bloom	Second Bloom	Third Bloom	
TIBA*			11.60 b
TIBA plus Boric Acid**			12.06 b
TIBA	Boric Acid		1.73 b
TIBA		Ethrel***	5.33 b
Control			30.03 a

* 15 ppm

** 10 ppm

***1,000 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

at two times), although not significant, was much lower.

Immature fruit

Again, all treatments reduced the yield below that of the control (see Table 30) although the TIBA and TIBA plus boric acid (the chemicals were applied together) treatments did not reduce it significantly. The greatly reduced yield of the TIBA-boric acid (split application) treatment is significant in this case.

Total

The same pattern as seen before is most apparent in Table 31. The TIBA and TIBA plus boric acid treatments were lower but not significantly different from the control. The TIBA-Ethrel treatment was significantly lower and the TIBA-boric acid (split application) treatment was lowest.

Quality Evaluation

Ripening characteristics

No test of ripening characteristics was made due to frost damage.

Handling characteristics

No difference resulting from the treatments on the ability of the fruit to withstand mechanical handling or on the market quality of the fruit was noted by observation.

Bioassay of Auxins in the Fruit

Effect of extract on coleoptile sections

The effect of treated and untreated fruit extracts on the growth of Avena coleoptile sections is presented in Table 32. From these data it can be seen that

Table 30

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE WEIGHT OF IMMATURE FRUIT PER PLOT--FALL, 1969

Time of Application and Chemical			Average Yield (pounds) +
First Bloom	Second Bloom	Third Bloom	
TIBA*			9.30 ab
TIBA plus Boric Acid**			10.40 ab
TIBA	Boric Acid		1.76 c
TIBA		Ethrel***	6.33 bc
Control			13.16 a

* 15 ppm

** 10 ppm

***1,000 ppm

+ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 31

EFFECT OF CHEMICAL, CONCENTRATION AND TIME OF APPLICATION ON THE AVERAGE TOTAL WEIGHT OF FRUIT PER PLOT--FALL 1969

Time of Application and Chemical			Average Yield (pounds) ✝
First Bloom	Second Bloom	Third Bloom	
TIBA*			23.17 ab
TIBA plus Boric Acid**			26.53 ab
TIBA	Boric Acid		3.63 c
TIBA		Ethrel***	14.96 b
Control			41.83 a

* 15 ppm

** 10 ppm

***1,000 ppm

✝ Numbers followed by the same letter(s) are not significantly different at the 5 percent level.

Table 32

LENGTH OF AVENA COLEOPTILE SECTIONS AFTER TWENTY-FOUR HOURS IN MEDIA CONTAINING INDOLE EXTRACTS OBTAINED FROM ETHREL TREATED AND UNTREATED FRUIT DURING CHAMBER RIPENING

		Time of Extraction After Treatment			
		One Week	Two Weeks	Three Weeks	Four Weeks
Treatment	Initial	Length of Sections (millimeters)			
Ethrel Dip (400 ppm)	---	1.1	1.1	1.1	---
	---	1.2	1.0	1.4	---
	---	1.0	1.1	1.2	---
	---	1.0	1.2	1.2	---
	---	1.1	1.1	---	---
	---	1.0	1.0	---	---
Average	---	1.06	1.08*	1.22*	---
Water Dip	1.0	1.4	1.1	1.1	1.0
	1.0	1.2	1.1	1.0	1.0
	1.0	1.3	1.1	1.2	1.0
	1.1	1.2	1.1	1.0	1.0
	1.0	1.1	1.0	1.1	1.0
	1.0	1.1	1.0	1.0	1.0
Average	1.02	1.21*	1.06	1.06	1.00
IAA Standard (10^{-3}M)	1.1				
	1.2				
	1.2				
	1.2				
	1.1				
	1.1				
Average	1.15*				

* Differs significantly at the 5 percent level from the initial length of 1 millimeter.

the 400 ppm Ethrel dip results in fruit extracts when taken at two and three weeks after treatment which significantly increase the length of Avena coleoptile sections, indicating an increase in indole-auxin activity. Two replicates were lost in the three week extraction due to inadequate coverage of the sections by the buffer solution. An initial extraction was not made and a four week extraction could not be made due to the overripe and diseased condition of the fruit.

The water dip produced an increased indole-auxin activity at one week, and an IAA standard buffer solution produced the expected increase in coleoptile length.

Spring 1970

Harvest Method Comparison

Initial solution of model

Using the results of the spring 1969 experiment, yield values for machine harvest (Y_2) and machine harvest of chemically treated fruit (Y_3) were estimated as a sum of the percent of total for the categories breaker through pink from the first harvest; light red through ripe, breaker through pink and mature green from the second harvest. Therefore, it was assumed that 84.30 percent of the total yield could be recovered from an untreated mechanical harvest and 86.55 percent of the total yield could be recovered from the boric acid-Ethrel treated fruit. These figures were actually derived by adding the significant differences between the treatment and control in the breaker through pink category for the first harvest, light red through ripe and mature green categories for the second harvest. This sum (2.25) was then added to the control percentage. There may be some question as to the significance of this figure, although it was sufficient for the purpose of the model. It was felt that these categories would represent the fruit recovered from a once-over harvest. However, with the expected greater loss from mechanical handling, the raw yield percentages were reduced to 70 percent for mechanical harvest and 72.25 percent for mechanical harvest of chemically treated fruit. Converting this to the Immokalee-Lee area base (28), the yields Y_2 and Y_3 were set at 185.0 crates (40 pounds) per acre and 191.0 crates (40 pounds) per acre, respectively.

The mixed integer method of solution was not possible with the MPS 360 program. In order to solve the model using the simplex algorithm allowed for in the MPS 360 program (115), it was assumed that the cost of the mechanical harvester and support equipment had been incurred so that the fixed cost of the equipment was a permanent part of the objective function. The resulting solution would then agree with a Q equal to one. For Q equal to zero the only option was hand harvest, and this solution was derived manually.

The initial tableau and the optimal solution appear in Table 33. Here it is seen that, for the conditions set in the tableau, the optimal solution, or maximum revenue for this function, was at 29.67 acres of tomatoes for hand harvest, no acres of tomatoes for machine harvest and no acres for machine harvest of chemically treated fruit. Thus it is not feasible for the grower to use any of the mechanical harvest techniques studied under the initial conditions. It can also be seen from the solution that all of the labor was used, 29.67 acres were used and the total yield was 7,837.15 crates (40 pounds) which produced a "net revenue" of $13,117.43.

Parametric programming

The changes that occurred in the solution when certain of the parameters were changed are presented in Table 34. Comparisons between X_2 and X_3 were made with the MPS 360 program; however, due to the inability of the program to accept a

Table 33

INITIAL TABLEAU AND OPTIMAL SOLUTION OF A LINEAR PROGRAM MODEL FOR EVALUATION OF THREE TOMATO HARVEST METHODS*

	Harvest Methods									
Restraints	Hand		Machine		Machine plus Treatment		Yield (40# crates)	Q		Limits
Acreage	X_1	+	X_2	+	X_3		0	0	LE**	50 acres
Yield (40# crates)	$- 264.00X_1$		$- 185.00X_2$		$- 191.00X_3$	+	X_4	0	=	0
Labor (man-hours)	$117.90X_1$		$+ 57.93X_2$		$+ 58.68X_3$		0	0	=	3500 man-hours
Q	0		0		0		0	1	=	1 or 0
Objective Function	$-\$218.13X_1$		$-\$114.64X_2$		$-\$132.67X_3$		$+\$2.50X_4$	$-\$6,574.00Q$	=	Z

Optimal Solution

Activity	Amount	Restraint	Amount Used
X_1	29.67 acres	Acreage (A)	29.67 acres
X_2	0	Labor (SL)	3500 man-hours
X_3	0		
X_4	7,837.15 crates		
Z	$13,117.43		

*Rounded to two decimal places

**Less than or equal to

Table 34

CHANGES IN OPTIMAL SOLUTION DUE TO PARAMETRIC PROGRAMMING OF CERTAIN PARAMETERS PRESENTED IN TABLE 32*

Parameter Varied	Range	Value	Activity	Amount	Restraint	Limit	Amount Used
A	25-275	25.00	X_1	25.00	Labor	50000	2947.00
			X_2	0			
			X_3	0			
			X_4	6600.00			
			Z	$11046.75			
		50.00	X_1	50.00	Labor	50000	5895.00
			X_2	0			
			X_3	0			
			X_4	13200.00			
			Z	$22093.50			
		X_1 increases to maximum					
SL	3000-9600	3000.00	X_1	0	Acreage	100	51.79
			X_2	51.79			
			X_3	0			
			X_4	9580.53			
			Z	$11440.50			
		3300.00	X_1	0	Acreage	100	56.97
			X_2	56.97			
			X_3	0			
			X_4	10538.58			
			Z	$13241.95			
		X_2 increases to maximum					
Y_2	185-264	193.54	X_1	10.06	Acreage	50	50.00
			X_2	39.94	Labor	3500	3500.00
			X_3	0			
			X_4	10586.33			
			Z	$13118.67			
Y_2	185-264	222.62	X_1	0	Acreage	50	50.00
			X_2	50.00	Labor	3500	2896.50
			X_3	0			

Table 34 continued

Parameter Varied	Range	Value	Activity	Amount	Restraint	Limit	Amount Used
			X_4	11130.20			
			Z	$15519.50			
Y_3	191-264	206.06	X_1	9.56	Acreage	50	50.00
			X_2	0	Labor	3500	3500.00
			X_3	40.44			
			X_4	10857.31			
			Z	$13118.78			
Y_3	191-264	229.81	X_1	0	Acreage	50	50.00
			X_2	0	Labor	3500	2934.00
			X_3	50.00			
			X_4	11490.50			
			Z	$15518.75			
a_3	115-185	115.00	X_1	9.56	Acreage	50	50.00
			X_2	0	Labor	3500	3500.00
			X_3	40.44			
			X_4	10247.70			
			Z	$12309.59			
		128.45	X_1	10.06	Acreage	50	50.00
			X_2	39.94	Labor	3500	3500.00
			X_3	0			
			X_4	10045.00			
			Z	$11765.06			
P	2.50-5.00	3.34	X_1	9.56	Acreage	50	50.00
			X_2	0	Labor	3500	3500.00
			X_3	40.44			
			X_4	10247.70			
			Z	$20194.10			

mixed integer problem, comparisons including X_1, under restrained conditions were made by hand. Used in the manual solutions were the objective function and the marginal rate of substitution -- inverse price ratio expression.

Restraint changes

When the acreage value was increased at 25 acre intervals from 25 to 275 acres with labor essentially unlimited, it is seen that the model added more X_1 and used no other harvest methods. When acreage was unlimited and labor varied from 3,000 to 9,600 man-hours in 300 man-hour steps, machine harvest was the only method used and X_2 was increased to the maximum possible. Only when both acreage and labor were limiting, was a mixture of hand and machine harvest found.

Yield changes

As all other factors were held constant and the yield from the machine harvest method (Y_2) was increased, it is seen that when the yield of the machine harvest reached 198.54 crates per acre, a hand harvest, machine harvest (X_1, X_2) mixture became more profitable than all hand harvest. With a continued increase of Y_2 to 222.62 crates per acre, machine harvest (X_2) became the only method employed. When Y_3 was varied from 191.00 crates per acre to 264.00 crates per acre, it is shown that a yield of 206.06 crates per acre was required for the chemical treatment method (X_3) to replace X_2 and maintain a more profitable mix than all X_1. Not until Y_3 reached 229.81 crates per acre did X_3 become the single most profitable activity.

Cost changes

The threshold cost, or the cost that results in a change from one method to the other, was found to be \$128.45 for a_3. That is, as the cost of the chemical treatment and mechanical harvest was increased from \$115.00 to \$185.00, when it reached \$128.45, X_3 was replaced by X_2 in the solution. Or, conversely, if the cost of the chemical treatment and mechanical harvest could be reduced to less than \$128.45, it would replace X_2. However, it is seen that, at both of these costs, the profits are less than the initial solution; in fact, a_3 must be reduced to less than a_2 (an infeasible proposition) before an X_1, X_3 mix is more profitable than all X_1.

Price changes

Here it is evident that, under the restraints of the initial tableau, when the price per crate (P) reaches \$3.34, X_3 replaced X_2. The new mix is also more profitable than all X_1 with the new price.

DISCUSSION

Effects of Field Treatments

Single Applications

Ascorbic acid

Little can be said as to the effect of ascorbic acid treatments on the yield of tomato from the results of this observational trial. However, the indicated lower yields and inconsistant effects on fruit quality parameters did not demonstrate a similar activity to Ethrel. Thus the concept of ascorbic acid working through an increased output of ethylene (45) did not seem to hold in this application. Indeed, it is quite likely that the wide difference in concentrations used appears to be too great. Much more investigation is required to evaluate the effects of ascorbic acid.

Boric acid

Yield effects

Although there were no significant differences in the total yields of the spring 1969 experiment, the suspiciously higher yield of the boric acid treatment indicated an incipient boron deficiency, yet the lack of response in the treatments with boron in combination indicated boric acid had an effect besides fertilization which was masked by the combined treatments.

In order to better approach this problem, the data were converted to percent of the total and, at that, all significant increases among the various maturity classifications from the boric acid treatment disappeared. It then appears that, in this case, the response to boric acid was one of a general fertilizer response or perhaps more directly through an increase in sugar translocation. Went (175) and others (9, 14) have demonstrated an increase in tomato flower production as a result of an increase in sugar translocation to the developing inflorescences. Gauch and Dugger have postulated (60) that a major role of boron in plant metabolism is an enhancement of sugar translocation through the formation of a sugar-borate complex or as a constituent of the membrane. Therefore, with boron fertilization, there may be an increase in flower production in boron-deficient plants. Although none of the symptoms associated with boron deficiency (116) were noted, the effect of the treatment was similar to that observed in pears (17) where an increase in fruit set due to boron treatments could not be attributed to a stimulation of pollen germination and tube growth alone.

The increase in yield was not uniform throughout every category: the light red to ripe and breaker to pink categories of the second harvest showing the greatest increases in absolute yield. These categories represent the flowers that were being formed at about the time the treatment was made, and since boron is generally considered immobile (133), the plants received the greatest benefit from a single foliar application at this time.

Quality effects

Although boron has been reported (61) to have some relationship with carotene, it was not evident in the a/b color ratios.

An increase in soluble solids content of the fruit from plants treated with boric acid is expected in the light of the theory of Guach and Dugger. Since the growing tomato fruit is an active "sink," one would expect that boron treatments would increase the sugar content of the fruit by increasing the translocation to that organ. Some researchers (173) believe that the boron effect is not an enhancement of translocation but a facilitation of sucrose uptake. However, since, in the experiments performed by this author, no sucrose was applied, the increase in soluble solids can be interpreted solely as one of increased sugar translocation. The increase in soluble solids was evident only in the locule of the fruit in the first harvest. As was mentioned previously, boron is considered relatively immobile and, again, the fruit already formed at the time of treatment received the benefit of increased sugar translocation and the boron was no longer available for large scale reuse. The locular portion of developing tomato fruit is considered (19, 63, 67) as the more physiologically active area and thus would be more likely to demonstrate the result of an increase in sugar translocation. The general differences between the locular and pericarp portions as found in this experiment were similar to those found by other workers (67, 71, 95).

Although the effects of boron are well defined in relation to sugar translocation and carbohydrate metabolism, particularly in meristematic areas (61), the relationship to other physiological processes is not. This makes the explanation of the differences in pH and titratable acids more difficult. However, at least in the first harvest, the lower pH of the locular area may reflect an increase in organic acids. Since the major acid components of the tomato fruit are also the major components of the Krebs cycle (95), the increase in acidity due to boric acid treatments could be a result of the higher sugar content providing an increase in substrate. This should also be borne out by a higher titratable acidity but is not. The general rule (95) of an inverse ratio of pH to titratable acidity is shown in the second harvest although the results were opposite those of the first harvest, i.e., a high pH and low titratable acidity. This also could be explained in terms of the higher soluble solids of the first harvest. If it is assumed that the photosynthetic ability was lower in the later stages of the season, with an increased fruit load, and the ability to produce and transport carbohydrates further reduced by the disruptive harvest procedure; and if a greater than normal amount of substrate were removed in the first harvest due to an increase in sugar translocation, then it follows that there was less substrate to enter into the Krebs cycle. This, however, was not supported by a significantly lower soluble solids content of the fruit of the second harvest.

Calcium chloride

Yield effects

Since there was no significant difference in any of the categories as a result of the calcium treatment either in absolute or relative yields, there was obviously no fertilizer or pollen germination effect.

Quality effects

The lowering of the titratable acidity of the pericarp of the fruit of the first harvest and locule and pericarp of the second harvest fruit can perhaps best be explained in terms of an inactivation of the organic acids. The precipitation of oxalic acid by calcium is well known (51) and it appears that this occurred in these fruit, resulting in a decrease of free organic acids.

This removal of organic acids from metabolism could be the cause of the lower soluble solids. As the fruit ripened in storage, there was no translocation to replace the carbohydrates used in respiration and maturation and with some of the organic acids being permanently lost more than the normal amount of carbohydrates (measured as soluble solids) was required as substrate to replace them.

Duraset

Yield effects

Duraset has been suggested (157) to have an auxin-like activity. The results of the fall 1968 experiment seem to bear this out, at least with the later application, for the results from the IAA application (10 ppm) and the Duraset application (100 ppm) were the same--an increase in the number of ripe fruit. Since no significant effect was found in any of the other categories or in the total it is difficult to say with certainty whether Duraset acted by preventing abscission of the flowers and newly formed fruit as would befit an auxin-like activity (2, 9, 11) or by increasing the number of flowers in the inflorescences developing after the application (157). A third and more substantial possibility exists. Abeles and Rubenstein (5) have shown that an auxin (napthaleneacetic acid) will stimulate ethylene production in young tomato fruit. Therefore, Duraset, if acting as an auxin, may have caused an increase in ethylene evolution and a concomitant increase in the rate of ripening, a well known result of ethylene applications (20). This would account for the lack of differences in the total yield; however, the expected decrease in yield of the mature green category resulting from a shift to the light red and ripe category was not found.

It is curious that the lower concentrations produced a response while the higher concentrations show no effect--either a greater response or a toxicity effect. Tomato plant growth is slow during the fall season as a result of more severe weather conditions and the plants may be more sensitive to hormonal applications and yet show no sub-lethal foliar symptoms.

The adverse weather conditions of the fall season, particularly cold, may account for the response to Duraset in the fall but not in the spring. The greatest success with Duraset and other floral hormones has been in northern or typically cool areas (120, 121, 126, 156, 168, 172) while less success has been obtained in warmer climates (54) where flower production and fruit set are not curtailed by suboptimal temperatures (174). Of course, the spring application was made at a different time (more in accordance with the northern recommendations (157)) than the successful fall application.

Quality effects

The firmer fruit produced by the Duraset treatment,as evidenced by the increased force required to shear a sample, did not follow either the effects expected from an auxin treatment (5, 80, 87) or the results found with Duraset-like materials (54). In all of these cases, softer fruit are expected due to the acceleration of ethylene as noted by Abeles and Rubenstein (5) and the resultant more mature (softer) fruit. In fact, Abeles (4) has concluded that a major role of ethylene is to regulate the production of cellulase, and,by increasing ethylene, cellulase (a cell wall degrading enzyme (19)) also increases. Auxins (IAA) have also been found to stimulate cellulase production (55). In the face of this evidence, it is difficult to explain the results obtained here. One possible explanation is that the early application of Duraset may have produced some retardant effect on the genetic control mechanism that governs the enzyme complex responsible for fruit softening. This is fecsible in that the applications were made at or prior to the gametic and embryonic stages of the fruit tested. The only recognizable pattern that was found in the soluble solids, pH and titratable acidity of the Duraset treated fruit, is that in the first harvest they were generally higher and in the second harvest they were generally lower. This was also somewhat the pattern found in the later Ethrel treated fruit and points to a similarity and possibly some small ethylene stimulation by the Duraset treatments. It is a tenuous comparison, however, in the face of the effects on the firmness of the fruit and the early application time of the Duraset treatments, yet there is not necessarily a correlation between fruit softening and the other parameters; they may be governed by separate mechanisms.

Emery C-9

The higher concentration of this material reacted in a manner very similar to the 10 ppm IAA treatment, and suggests a similar activity, although no change in fruit quality was observed. Little else is known about this material.

Ethrel

Yield effects

In the fall 1968 trials, it was found that an increased number of light red and ripe fruit were produced by the second bloom application of 600 ppm Ethrel. This is probably due to an increase in the ripening rate of the treated fruit as has been found characteristic of this material (83, 84, 136, 146).

The rates were increased in the spring 1969 experiment and the time of application was delayed. These actions were designed to create a definite separation between the early and late fruit and to cause the abscission of the late developing flowers (84, 102).

In examining the results, the expected increase in early ripe fruit was found, although it is also seen that the later application of Ethrel had the greater effect on the early yield (highest per cent of light red and ripe in the first harvest and highest first harvest yield). It is known that the sensitivity of tomato tissue to ethylene varies with age (5,106) and that a certain physiological stage is necessary before all ripening processes will take place (106) when stimulated by ethylene. Thus the later application of Ethrel was made at a time when the fruit were more mature and demonstrated a direct, more natural, ripening response--the fruit were beyond the required stage. The subsequent yields in the mature green category that were lower than the early Ethrel and control yields, further indicated the advancement of ripening and shift of fruit from later stages. The non-significant differences in the breaker through pink category may have reflected the lack of a consistent discrimination in sorting.

The earlier application of Ethrel produced much the same pattern as the later application; however, its effect is seen primarily on the fruit of the second harvest and,in light of the minimum maturity requirement already discussed, it is difficult to reconcile the effects as directly on the ripening of the fruit. Perhaps in whole plant applications,prior to the "critical maturity" stage, a disposition to early ripening was created by ethylene applications.

The abscission inducing effects of Ethrel were not demonstrated in a reduced yield of immature fruit. It is evident, as pointed out by Iwahori and his co-workers (84), that only the unfertilized flower is sensitive to ethylene and apparently so few of the flowers were at a vulnerable stage during the precise time of a single Ethrel application that the effects on the yield were negligible.

Quality effects

The effects on quality by the two Ethrel applications were very similar except that the later application affected the earlier fruit and the earlier application affected the later fruit--a pattern identical to that noted in the yield effects. In general, the later application of Ethrel increased soluble solids and pH and decreased titratable acidity of the first harvest (the exceptions are pericarp pH and locule titratable acidity). The early application produced much the same results with the second harvest fruit. Some of the effects of the later application of Ethrel also extended into the second harvest. Crane (47), in demonstrating that ethylene has a mobilization effect on nutrient entry in the fruit,offers an explanation for the pattern of results obtained with Ethrel treatments. By increasing the movement of substrate into the fruit from the plant a higher soluble solids content,as found here, would result. However, one would also expect a higher organic acid content,as discussed in reference to boron, which was not found.

Fatty acid ester

The high concentration of the fatty acid ester, later application, produced an effect similar to Duraset, Emery C-9 and IAA; no other observations were made on this material so few conclusions can be drawn as to its activity.

Gibberellic acid

Yield effects

The gibberellic acid treatment appears to have had no effect on the yield, contrary to other research (131); however, this was a non replicated trial and results are not conclusive.

Quality effects

The gibberellic acid treatment appears to be the only one that produced a major effect on the bio-yield point. However, it is highly probable that the fruit from this treatment were not of the same maturity as the others. As has been demonstrated (52), gibberellin delays the ripening of tomatoes, and an antagonism between gibberellin and ethylene (initiator of ripening (20)) has been suggested (144). Thus it is likely that the fruits tested in the bio-yield determination were not at the breaker stage, although they appeared of the same maturity as the others tested. The higher force required to puncture the gibberellic acid treated fruit then reflected the higher force required to puncture a mature green fruit. The delay in maturity (or firmer flesh) was indicated in the shear force measurements although the measurements were not made under sufficient replication.

The gibberellin-ethylene antagonism was not evidenced in the effects of these two treatments on soluble solids, pH and titratable acids. The gibberellic acid and comparable later Ethrel treatments produced very similar results on the fruit quality parameters.

IAA

The lower concentration of IAA produced the expected increase in early yield (120, 126, 130, 148) and even though the activity of this material is well documented, it was included in the preliminary trials as a comparative treatment. The use of this material in commercial application for fresh market mechanically harvested fruit was not considered because the danger of parthenocarpic and thus poorer quality fruit (80, 87, 88) was too great.

TIBA

The TIBA treatment reduced the yield in every category and did not appreciably concentrate the yield into any one category. This yield reduction appears to be due to the initial stunting of the plants. TIBA has been found (69, 124, 125) to inhibit the polar transport of auxin; thus producing an auxin toxicity in the areas of synthesis (150, 159) and a deficiency in the areas of utilization and result in the loss of apical dominance. This accounts for the aberrant growth (58, 94) noted in foliar areas and the conversion of vegetative to floral buds in nondeterminant plants (184). The prevention of auxin translocation to the abscission zone would also account for the abscission-inducing activity (176) of TIBA. The stunting of the tomato plants noted in this experiment would undoubtedly have been due to the lack of auxin translocated to the growing point and the floral buds. The slower growth of tomatoes in the fall season would account for the increased sensitivity and slower recovery from the TIBA treatment.

The fasciation effect is not well researched; however, it is possible that the cause of the fasciation is a lack of the auxin concentration required for adequate differentiation.

Little abscission was noted in this or other treatments; it appears that the tomato flower, once fertilized, is relatively insensitive to hormonal applications, pointing to the importance of the endogenous hormones synthesized by the developing embryo (47).

Combined Applications

Duraset-Ethrel

Yield effects

There appears to be an antagonism between these two materials. The Ethrel effect was completely negated by Duraset, producing a yield pattern no different than the control. An auxin-ethylene antagonism has been alluded to by many authors (1, 5, 32, 36, 68) and it appears that Duraset has acted as an auxin in these experiments and blocked the activity of Ethrel (ethylene). It is hard to reconcile the time differences encountered in these experiments, for it seems inconceivable that the Duraset (auxin) level could remain artificially high throughout the season. Perhaps, as suggested in reference to the Duraset effect on the firmness of the fruit, the early treatments had a repressive effect on one or many of the genetic mechanisms governing ripening that exogenous applications of ethylene (Ethrel) were not able to overcome.

Quality effects

The antagonism between these two materials still exists in some of their effects on fruit quality parameters. However, here, Ethrel has the dominant influence--producing less firm fruit. In lowering the soluble solids and acidity measures of the first harvest and raising the soluble solids and acidity measures of the second harvest, Ethrel in this treatment produced effects similar to the early Ethrel treatment and countered the Duraset effects which were more like the later Ethrel treatment.

Duraset-boric acid

Yield effects

No significant yield effects were noted with this treatment, although the pattern was similar to the early Ethrel treatment.

Quality effects

The boric acid addition had effects slightly similar to the Ethrel addition--

lowering the soluble solids and acidity values produced in the first harvest by the Duraset treatment alone, and increasing the parameter values in the second harvest. If the interpretation of the function of Ethrel and boron as mobilizers of substrate is followed, then it is not surprising that the results appear this way. In the case of the soluble solids of the first harvest fruit, the mobilization may even have been to the second harvest fruit at the expense of the earlier fruit.

Duraset-boric acid-Ethrel

Yield effects

Since Duraset alone failed to show any effect on yield, the major effects in this treatment should be attributed to the boric acid-Ethrel addition. The increase in yield for the first harvest and early stage of the second harvest was identical to that of the boric acid-Ethrel combination and is discussed in more detail in reference to that treatment.

Quality effects

Boric acid and Ethrel would be expected to work in concert in modifying the quality parameters and this is what was found. The results from the Duraset-boric acid-Ethrel combination were very similar to those seen in the boric acid-Ethrel combinations. Thus it is evident that these two materials overrode the influence of Duraset.

Boric acid-Ethrel

Yield effects

This treatment produced results that look, in effect, as if the early and late Ethrel treatments were combined, for both the first and early second harvest relative yields were increased. It is evident that this was a synergistic effect in that the results of the two chemicals applied alone could not be superimposed to give the same results as the combined treatment. Since there was no evidence of an increased early yield in the boric acid treatments, and since ethylene is considered the major factor governing fruit ripening (20, 33, 34), it is assumed that the boric acid altered the fruit physiology in some way that facilitated the action of Ethrel on the first harvest fruit. Three possible explanations exist for this boron effect. First, the boron could have increased the auxin activity (53) of the first harvest fruit (these were the fruit beginning to develop at the time of treatment) which in turn stimulated some endogenous ethylene production (5). Secondly, by an increased sugar and hormonal translocation (61) the boron could have enhanced the exogenous ethylene (Ethrel) activity. Finally, a more involved explanation, but one that takes into account the time differential, would extend from the observation that boron applications to apple trees delay the climacteric (61). As discussed earlier, there is a difference in activity between the early and late applications of Ethrel. The early application affected the second harvest fruit, and it is suggested that these fruit were below the critical maturity stage for ethylene to directly stimulate ripening and were actually "predisposed" to early ripening. The first harvest fruit were unaffected by the early application for they were not yet past the critical stage, but were beyond the "predisposition stage." If boron treatments delayed these stages in the immature fruit, as it does the climacteric in ripening fruit, it would have postponed the predisposition stage and thus allowed the early Ethrel treatments to exert a predisposing influence. These stages could correspond to the changes in slope of the growth curve (47).

Quality effects

The "double Ethrel" application effect of the boric acid-Ethrel treatment was borne out by many of the changes in the fruit quality parameters. The first harvest fruit, not affected strongly by the single early Ethrel application, showed a marked similarity to those treated with the later Ethrel application.

Boric acid-calcium chloride

Yield effects

No significant effects were found in the relative yields of any categories due to this treatment.

Quality effects

The only significant effect on the quality parameters of this treatment was a lowering of the titratable acidity of the second harvest fruit. This may again be indicative of a calcium precipitation of some of the organic acids.

As has been pointed out (90, 133) there is an antagonism between boron and calcium in the plant and it appears that these two materials have mutually cancelled their effects.

TIBA-boric acid (simultaneous application)

Little difference exists between this treatment and the TIBA alone. As already discussed, the slower fall growth makes response to foliar applications less dramatic (albeit often more sensitive) and in this case a possible fertility response to boric acid is not evident.

TIBA-boric acid (split application)

The later boric acid application was observed to further slow the recovery from TIBA symptoms: preventing the plant from developing much foliage or producing many flowers. No toxicity symptoms were evident, and it is concluded as suggested (61) that boron played a role in enhancing the TIBA effects on the meristematic areas. This is further supported by the lower yield of the immature fruit.

TIBA-Ethrel

The Ethrel addition was unsuccessful in altering the yield patterns of the various maturity classes, pointing again to the particular unresponsiveness of plants grown under adverse weather conditions. The reduction in total yield by this treatment may have been indicative of a significant flower loss by abscission of the later blossoms as evidenced by the lower immature yield.

Bioassay

The increase of indole-auxins under Ethrel treatment seems to belie the concept of auxin-ethylene antagonism discussed previously. However, Burg and Burg (36), in exploring the long term effects of ethylene and auxin, concluded that ethylene inhibited the polar transport of auxin. In order to explain this anomoly the classical definition of a hormone (13, 15) must be used. Here a phytohormone (auxin) is defined as a substance synthesized in one area of the plant (in minute amounts) and translocated to another area where it exerts its influence. In this case, the ethylene (Ethrel) prohibited the translocation of auxin from the site of manufacture (probably the embryo) to the site of utilization and presumed degradation. Thus the auxin remained in the fruit in a non-utilized form. Since no quantitative measures of ripeness were taken in this experiment, the stage of ripeness being subjectively determined, it is difficult to say what, if any, effect the auxin imbalance had. It is equally difficult to determine if the higher auxin concentration was an artifact of an abnormally high ethylene level.

The lack of response at the first week extraction of treated fruit is difficult to explain in the above terms. A possibility exists that the one week delay in auxin occurrence may be a result of the one week acceleration of ripening by Ethrel (129). At least part of the activity of ethylene could be the repression of auxin production as well as auxin transport.

The auxin found in the non-treated fruits at one week probably corresponded to the 30 day peak found by Iwahori (82).

Although this experiment did not provide much information for use in explaining the field results, it does point out that ethylene has an effect on auxin levels as well as auxin having an effect on ethylene levels.

Harvest Comparison

Initial Solution

Under the conditions set in the initial solution it was not economically feasible for the individual grower to utilize any mechanical harvest method. However, an important point to recognize in this solution is that the assigned labor supply was arbitrary and under more limiting circumstances, as discussed later, the solution could change to greater utilization of machine harvest.

Parametric Programming

The results of programming the acreage and labor restraints illustrate an axiom of economics; that is, to restrict the input of scarce resources and use as much of the unrestricted or "free" resources as possible. Thus with unlimited land and limited labor, the labor conserving method, machine harvest, was employed. This would reflect the situation in the tomato industry at the present, where labor is becoming limited and land is not yet a limiting factor. On the other hand, when land was limiting and labor was unlimited, the hand harvest method was used exclusively. Another observation on this solution is that when either one of the restraints was unlimited, there was no mixture of activities in the solution; it is either hand or machine harvest.

In varying the yields, it is seen that a yield of 198.54 crates per acre was required in order to employ any machine harvest and that a yield of 222.62 crates per acre for the machine harvest method was necessary for the machine harvest method to completely replace the hand harvest method. This is important in evaluating research data in that any harvest method evaluated must produce a yield equivalent to 84.3 percent of a hand harvest yield in order for it to completely replace hand harvesting. A yield of 206.06 crates per acre or a 11.4 percent increase over the present mechanical harvest yield is required for any chemical method with the assigned costs to replace a nonchemical machine harvest method with a 70 percent of hand harvest recovery when the price is $2.50 per crate. The 2.5 percent increase derived for the boric acid-Ethrel method is seen not to be enough.

If, on the other hand, the cost of the boric acid-Ethrel method is reduced below $128.45, it will replace the mechanical harvest alone, but with the other initial values it will never become economically feasible.

Finally, if the grower could expect a price of $3.34 per crate, the chemical method would be profitable to use in combination with hand harvest.

The above changes in the solution with changes in the parameters illustrate the need for accurate evaluation of the parameters, for if a particularly important value such as cost or yield of the chemical method were not known precisely, the solution could change drastically.

SUMMARY AND CONCLUSIONS

Three field experiments were conducted to test certain floral zone affecting chemicals, alone and in combination, as to their activity in producing a uniform maturity in tomatoes (Lycopersicon esculentum Mill.) for a once-over mechanical harvest. Times of application, concentrations and effects on the quality parameters of bio-yield point, texture, soluble solids, pH and titratable acidity were also evaluated. The chemicals tested were ascorbic acid, boric acid, calcium chloride, Duraset, Emery C-9, Ethrel, fatty acid ester, IAA and TIBA.

A laboratory experiment was conducted to evaluate the effects of an Ethrel dip on the auxin content of tomatoes in storage.

In order to evaluate the economic significance of the results of the field experiments, a mixed integer programming model was devised to compare hand harvest, machine harvest and machine harvest of chemically treated fruit. Land, labor, cost, yield and price restrictions were included in the model and parametric programming of certain of the coefficients and restraints was employed to test the sensitivity of the model.

Many of the field treatments affected the yields of various maturity classes; however, TIBA-boric acid and TIBA-Ethrel split applications were the only treatments that significantly affected the total yield and that effect was a yield reduction. The major effects on the maturity classes were by the Ethrel and boric acid-Ethrel treatments. Ethrel applied at the time of the fifteenth inflorescence increased the percent yield of the light red through ripe fruit and reduced the percent yield of the mature green fruit in the second harvest. Ethrel applied one week later increased the percent yield of the light red through ripe and breaker through pink fruit of the first harvest and reduced the percent yield of the mature green fruit of the second harvest. The boric acid applied at the second bloom (ninth internode) followed by Ethrel applied at the fifteenth inflorescence produced an increase in the percent yield of light red through ripe and breaker through pink fruit of the first and second harvest and reduced the mature green of the second harvest.

The effects on the quality parameters were erratic but generally supported the thesis that the early application of Ethrel affected the later fruit and the later application of Ethrel affected the early fruit and the boric acid-Ethrel combination affected both the early and late fruit. The boric acid-Ethrel treatment appears to be the only one with promise of an economic application. With further research on refinement of application times and harvest times, the increase of a once-over yield may become economically significant.

The expected abscission-inducing and fruit-setting responses were not evident, except in the TIBA-Ethrel treatment, pointing to the precise timing required in application and the major influence exerted by the developing embryo.

The laboratory experiment showed an increase in auxins due to Ethrel treatment at 2 and 3 weeks'extraction after treatment, and a natural increase in auxin at a 1 week extraction that was not evident in the treated fruit. This was attributed to an inhibition of auxin transport by ethylene.

In evaluating the economic import of the boric acid-Ethrel treatment with the mixed integer programming model, it was found that the 2.5 percent increase in yield over the mechanical harvest was not sufficient for its use under a 50 acre and 3500 man-hour restriction and with a price of $2.50 per crate. However, it was found that if the price was $3.34 per crate it would be useful. In addition, unless the yield from the machine harvest method was 84.3 percent of the hand harvest, some hand harvest would still be required in order to maximize revenue. Further parametric evaluation illustrated the need for a more reliable cost and yield estimate for the machine harvest of chemically treated fruit method in order to provide a correct evaluation. It was demonstrated, however, that this model was useful in evaluating experimental results as well as providing a valuable decision making aid for the grower.

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BIOGRAPHICAL SKETCH

William J. Southam was born on September 24, 1944, in Taft, California. He received his primary and secondary education from the public school system in Salinas, California, graduating from Salinas Union High School in 1962.

He did his undergraduate work at the University of California at Davis and received a Bachelor of Science degree, majoring in Agricultural Production with specializations in Vegetable Crops and Agronomy, in 1966.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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